SEISMIC HAZARD ZONE REPORT 056

SEISMIC HAZARD ZONE REPORT FOR THE POINT DUME 7.5-MINUTE QUADRANGLE, LOS ANGELES AND VENTURA COUNTIES, CALIFORNIA

2002

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

STATE OF CALIFORNIA
GRAY DAVIS
GOVERNOR

THE RESOURCES AGENCY
MARY D. NICHOLS
SECRETARY FOR RESOURCES

DEPARTMENT OF CONSERVATION
DARRYL YOUNG
DIRECTOR

DIVISION OF MINES AND GEOLOGY
JAMES F. DAVIS, *STATE GEOLOGIST*

SEISMIC HAZARD ZONE REPORT 056

SEISMIC HAZARD ZONE REPORT FOR THE POINT DUME 7.5-MINUTE QUADRANGLE, LOS ANGELES AND VENTURA COUNTIES, CALIFORNIA

DIVISION OF MINES AND GEOLOGY'S PUBLICATION SALES OFFICES:

Southern California Regional Office
655 S. Hope Street, Suite 700
Los Angeles, CA 90017
(213) 239-0878

Publications and Information Office
801 K Street, MS 14-31
Sacramento, CA 95814-3531
(916) 445-5716

Bay Area Regional Office
185 Berry Street, Suite 210
San Francisco, CA 94107-1728
(415) 904-7707

CONTENTS

ILLUSTRATIONS

EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Point Dume 7.5-minute Quadrangle, Los Angeles and Ventura counties, California. The map displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides over an area of approximately 50 square miles at a scale of 1 inch = 2,000 feet.

The Point Dume Quadrangle lies along the coast almost entirely in southwestern Los Angeles County. The area includes parts of the cities of Malibu and Westlake Village and the unincorporated communities of Malibu Lake and Cornell. The prominent coastal feature Point Dume is about 10 miles west of the Malibu Civic Center and 35 miles west of the Los Angeles Civic Center. Most of the land is steep and rugged terrain of the Santa Monica Mountains where elevations range from sea level to 2824 feet. Ridges with steep-sided canyons extend southward from the range crest toward the coastal area, which is characterized by broad, gently sloping, relatively continuous terrace surfaces above narrow to moderately wide beaches. Residential development is primarily concentrated along Escondido and Trancas beaches and on the coastal bluffs, terraces, and hillsides within the City of Malibu, which was incorporated in 1991. Other small residential communities are also present along county roads, between Latigo Canyon and Kanan-Dume Road, and in the Malibu Lake, Cornell, and Seminole Hot Springs areas. Most of the undeveloped land in the quadrangle is parkland managed by the National Park Service, California State Parks, Santa Monica Mountains Conservancy, and Los Angeles County.

The map is prepared by employing geographic information system (GIS) technology, which allows the manipulation of three-dimensional data. Information considered includes topography, surface and subsurface geology, borehole data, historical ground-water levels, existing landslide features, slope gradient, rock-strength measurements, geologic structure, and probabilistic earthquake shaking estimates. The shaking inputs are based upon probabilistic seismic hazard maps that depict peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years.

The liquefaction zone in the Point Dume Quadrangle is restricted to canyon bottoms near the coast, the beaches, and small areas in the vicinity of Malibu Lake. The large and varied assortment of rock units within in a very complex structural setting characterized by intense faulting and deformation in a deeply dissected terrain has produced widespread and abundant landslides. More than 500 landslides are included in the inventory. These conditions contribute to an earthquake-induced landslide zone that covers about 54 percent of the land in the Point Dume Quadrangle.

How to view or obtain the map

Seismic Hazard Zone Maps, Seismic Hazard Zone Reports and additional information on seismic hazard zone mapping in California are available on the Division of Mines and Geology's Internet page: http://www.consrv.ca.gov/dmg/shezp/

Paper copies of Official Seismic Hazard Zone Maps, released by DMG, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available for purchase from:

BPS Reprographic Services
149 Second Street
San Francisco, California 94105
(415) 512-6550

Seismic Hazard Zone Reports (SHZR) summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These reports are available for reference at DMG offices in Sacramento, San Francisco, and Los Angeles. **NOTE: The reports are not available through BPS Reprographic Services.**

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. They must withhold development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers (and their agents) of real property within a mapped hazard zone to disclose at the time of sale that the property lies within such a zone. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed DMG to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that 1) the process for zoning liquefaction hazards remain unchanged and 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

This Seismic Hazard Zone Report summarizes the development of the hazard zone map. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historical ground-water information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Point Dume 7.5-minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Point Dume 7.5-Minute Quadrangle, Los Angeles and Ventura Counties, California

By
Marvin Woods

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps developed by DMG in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within seismic hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Point Dume 7.5-minute Quadrangle. This section, along with Section 2 (addressing earthquake-induced landslides), and Section 3 (addressing potential ground shaking), form a report that is one of a series that summarizes production of similar seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazards zone mapping in California is on DMG's Internet web page: http://www.consrv.ca.gov/dmg/shezp/

BACKGROUND

Liquefaction-induced ground failure historically has been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge earthquakes, significant damage to roads, utility pipelines, buildings, and other structures in the Los Angeles area was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated, granular sediment within 40 feet of the ground surface. These geological and ground-water conditions exist in parts of southern California, most notably in some densely populated valley regions and alluviated floodplains. In addition, the potential for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region in general, including areas in the Point Dume Quadrangle.

METHODS SUMMARY

Characterization of liquefaction hazard presented in this report requires preparation of maps that delineate areas underlain by potentially liquefiable sediment. The following were collected or generated for this evaluation:

- Existing geologic maps were used to provide an accurate representation of the spatial distribution of Quaternary deposits in the study area. Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill
- Construction of shallow ground-water maps showing the historically highest known ground-water levels
- Quantitative analysis of geotechnical data to evaluate liquefaction potential of deposits
- Information on potential ground shaking intensity based on DMG probabilistic shaking maps

The data collected for this evaluation were processed into a series of geographic information system (GIS) layers using commercially available software. The liquefaction zone map was derived from a synthesis of these data and according to criteria adopted by the State Mining and Geology Board (DOC, 2000).

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils generally is confined to areas covered by Quaternary (less than about 1.6 million years) sedimentary deposits. Such areas within the Point Dume Quadrangle consist mainly of low-lying shoreline regions, alluviated valleys, and canyon regions. DMG's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth, which is gathered from various sources. Although selection of data used in this evaluation was rigorous, the quality of the data used varies. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone maps are intended to prompt more detailed, site-specific geotechnical investigations, as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth, density, and thickness of liquefiable materials, depth to ground water, rate of drainage, slope gradient, proximity to free faces, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to assess the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction and zoning evaluations in PART II.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

Point Dume Quadrangle covers approximately 50 square miles of land (plus 11 square miles of ocean) in western Los Angeles County. Approximately 0.3 square mile of land in the extreme northwest corner of the quadrangle lies within Ventura County. The cities of Westlake Village and Malibu are the only incorporated jurisdictions within the quadrangle. The City of Malibu extends 26 miles along the Pacific Ocean coastline, from Topanga and Malibu Beach quadrangles to the east, through Point Dume Quadrangle, to Triunfo Pass Quadrangle to the west. Although very long in its east-west (along-shore) dimension, within Point Dume Quadrangle, the city extends inland only approximately 2.7 miles at its widest point (at Point Dume). The rugged, deeply dissected Santa Monica Mountains cover most of the quadrangle except for the bench-like terrain north of Point Dume and elsewhere close to the coastline. The highest elevation within the quadrangle is 2824 feet at Castro Peak, which is located approximately 4.5 miles north of Escondido Beach.

Triunfo Canyon and its tributaries Lobo and La Sierra canyons and Medea Creek form the principal drainage system in the quadrangle, located in the northeastern corner. Malibu Lake, which lies behind a dam within Triunfo Canyon, is located near the eastern border of the quadrangle. Other significant drainages are Trancas, Zuma, Ramirez, Escondido, Latigo, and Solstice canyons, all of which drain directly into the Pacific Ocean and which are usually dry during the summer. Principal travel routes within the Point Dume Quadrangle are the Pacific Coast Highway (State Highway 1) and Mulholland Highway. Other important routes are Decker Road (State Highway 23), Encinal Canyon Road, Kanan Dume Road, and Latigo Canyon Road. The City of Malibu represents the principal developed (residential) area, most extensively expressed in the Point Dume area. Other, smaller developed residential areas within the highlands include Seminole Hot Springs (in La Sierra Canyon) and the Malibu Lake area. Except for approximately 1000 acres along the northern boundary, the quadrangle in its entirety lies within the Santa Monica Mountains National Recreation Area, which comprises noncontiguous tracts of public lands, including the westernmost part of Malibu Creek State Park. Other public lands include Robert H. Meyer Memorial State Beach, Zuma Beach County Park, and Point Dume State Beach. Solstice Canyon and Rocky Oaks, both of which were formerly county parks, are now managed by the National Park Service. The National Park Service is also responsible for a large tract of land in the Zuma Canyon-Trancas Canyon area.

GEOLOGY

Bedrock and Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. To evaluate the areal and vertical distribution of shallow Quaternary deposits and to provide information on subsurface geologic, lithologic and engineering properties of the units in the Point Dume Quadrangle, we relied on a 1:24,000-scale geologic map published by the U. S. Geological Survey (Campbell and others, 1996). This map was digitized by staff of the Southern California Areal Mapping Project and incorporated into DMG's GIS. The distribution of Quaternary deposits on this map (summarized on Plate 1.1) was used in combination with other data, discussed below, to evaluate liquefaction susceptibility and develop the Seismic Hazard Zone Map. Limited field reconnaissance was conducted to confirm the location of geologic contacts, observe properties of near-surface deposits, and characterize the surface expression of individual geologic units.

Table 1.1 summarizes the Quaternary map units recognized by Campbell and others (1996) within the Point Dume Quadrangle. Omitted from Table 1.1 and also from Plate 1.1 are undivided landslide deposits (Qls) and a single small debris-train deposit (Qdt) located on the south flank of Castro Peak. Approximately 10 percent of the land area in the quadrangle is covered by unconsolidated to moderately consolidated sedimentary deposits of Quaternary age (excluding Qls and Qdt deposits). Within approximately 2.5 miles of the tip of Point Dume and within about one-half mile of the coast away from the flanks of the point, upper Pleistocene marine and nonmarine coastal terrace deposits rest on three distinct erosional platforms cut into older bedrock (**Qtm** and **Qtn** in Table 1.1). Based on open-system uranium series dates on marine shells, Qtm and Qtn deposits are 104,000 to 230,000 years old (Birkeland, 1972; Campbell and others, 1996). The Qtn deposits are especially prominent west of Point Dume, where younger (Holocene (?) and upper Pleistocene) nonmarine coastal terrace deposits (**Qtny**) also occur. Holocene (?) and upper Pleistocene stream terrace deposits (**Qts**) are perched on the flanks of Trancas, Zuma, Ramirez, and Medea Creek canyons. For the most part all of these terrace deposits consist of gravel, sand, and silt that, because of their relatively old age, tend to be compact and dense. Also, because these deposits tend to occur in locally high topographic areas, ground water tends to be relatively deep within these deposits.

The remaining Quaternary deposits are relatively young, considered by Campbell and others (1996) to be of late Pleistocene to Holocene age, except in the case of artificial fill (**af**), which is strictly Holocene. Except for artificial fill, which occurs chiefly in roadways, the younger Quaternary deposits occur within or immediately adjacent to low-lying valley and canyon floors, or they form beach (**Qb**) and associated dune (**Qd**) deposits, both of which consist of unconsolidated, cohesionless, fine- to medium-grained sand. A distinctive Qd deposit covers about 27 acres of the lower coastal terrace at the tip of Point Dume at an elevation of approximately 150 feet. Undifferentiated alluvium (stream-deposited, unconsolidated, generally cohesionless gravel, sand, and silt; **Qal**) fills the bottoms of all canyons mentioned previously, as well as isolated reaches of many other, unnamed canyons. Locally, Campbell and others (1996) recognized two divisions of Qal: alluvium in active channels (**Qalc**, occurring only in the lowest reach of both Zuma and Ramirez canyons), and alluvium as fan deposits (**Qalf**, occurring primarily in side canyons of Zuma canyon). Relatively small, isolated patches of colluvium (**Qc**) and undivided alluvium and colluvium (**Qu**) occur throughout the northern half of the quadrangle. Qc deposits generally rest on lower hillslopes and generally consists of silt, sand, and clay, typically with abundant angular rock fragments. Qu deposits generally occur along the lower flanks of valleys and encompass the range of Qal and Qc lithologies.

Pre-Quaternary bedrock exposed in the Point Dume Quadrangle is almost entirely of Tertiary age, with some Cretaceous rocks exposed on the southern flank of the Santa Monicas (Campbell and others, 1996). The youngest Tertiary rocks (upper Miocene) are unconformably overlain by upper Pleistocene marine terrace deposits. Strata of Pliocene and early Pleistocene age are not present within the quadrangle. Bedrock within the quadrangle can be classified into two distinct stratigraphic sequences, separated by the Malibu Coast Fault. South of the Malibu Coast Fault, the sequence consists of the middle and upper Miocene Monterey Shale, overlying the Trancas Formation (detrital sedimentary rocks), which overlies and intertongues with the lower and middle Miocene Zuma Volcanics. All of these rocks appear to have been deposited in a marine environment. North of the Malibu Coast Fault, the middle Miocene Topanga Group comprises (in descending order) the Calabasas Formation (marine detrital sedimentary rocks), the Conejo Volcanics, and the Topanga Canyon Formation (marine and nonmarine detrital sedimentary rocks). Each of these formations contains several mappable members. These rocks conformably overlie the lower Miocene Vaqueros Formation (marine sandstone and interbedded nonmarine (?) mudstone), which in turn rests on and locally intertongues with the upper Eocene, Oligocene, and lower Miocene Sespe Formation (nonmarine detrital, characteristically reddish sedimentary rocks). The Sespe Formation conformably overlies marine detrital sedimentary rocks of the middle

Eocene Llajas (?) Formation and lower Paleocene Coal Canyon Formation, which in turn rests conformably on the nonmarine (?) Paleocene (?) Simi (?) Conglomerate, or, where the Simi is absent, directly (but probably disconformably) on turbidites and associated deep marine detrital sedimentary rocks of the Upper Cretaceous Tuna Canyon Formation. Basaltic and andesitic dikes and sills are intrusive to middle Miocene and older strata north of the Malibu Coast Fault. See the Earthquake Induced Landslide portion (Section 2) of this report for further details.

Structural Geology

The Point Dume Quadrangle lies within the Santa Monica Mountains, the southernmost range of the east-west trending Transverse Ranges geomorphic province. The Santa Monica Mountains have undergone fairly rapid uplift during the Quaternary as evidenced by the deeply incised stream canyons and by thrust faulting near the coast that places Tertiary bedrock over Quaternary marine and nonmarine terrace deposits (Campbell and others, 1996). Leveling surveys and GPS data indicate that the mountains are continuing to rise. All pre-Quaternary rocks in the quadrangle are folded and cut by faults. Faults across which this uplift has been accommodated include the Malibu Coast Fault, the Malibu Bowl Fault, Zuma Fault, and the Escondido Thrust Fault, all of which are east-west trending north-over-south reverse faults located within the southern Santa Monica Mountains (Campbell and others, 1996).

A more detailed discussion of the structural geology of the quadrangle is presented in Section 2.

ENGINEERING GEOLOGY

We obtained information on subsurface geology and engineering characteristics of sedimentary deposits from borehole logs collected from reports on geotechnical projects. For this investigation, we collected 32 borehole logs from the files of the City of Malibu and the Los Angeles County Public Works Department. We entered the data from all of these borehole logs into a DMG geotechnical GIS database (Table 1.1).

Standard Penetration Test (SPT) data provide a standardized measure of the penetration resistance of a geologic deposit and commonly are used as an index of density. Many geotechnical investigations record SPT data, including the number of blows by a 140-pound drop weight required to drive a sampler of specific dimensions one foot into the soil. Recorded blow counts for non-SPT geotechnical sampling, where the sampler diameter, hammer weight or drop distance differ from those specified for an SPT (ASTM D1586), were converted to SPT-equivalent blow count values and entered into the DMG GIS. The actual and converted SPT blow counts were normalized to a common reference effective overburden pressure of one atmosphere (approximately one ton per square foot) and a hammer efficiency of 60% using a method described by Seed and Idriss (1982) and Seed and others (1985). This normalized blow count is referred to as $(N_1)_{60}$. Of the 32 borehole logs entered into DMG's GIS database, only 16 had SPT or SPT-equivalent data.

Geotechnical borehole logs, as well as the geologic map by Campbell and others (1996), provided information on lithologic and engineering characteristics of Quaternary deposits within the study area. Geotechnical characteristics of the Quaternary map units are generalized in Table 1.1.

Geologic Map Unit	Material Type	Consistency	Age	Liquefaction Susceptibility*
af, artificial fill	variable granular materials	loose to dense	Holocene	very high to low
Qal, alluvium	sand, gravel, & silt	loose	Holocene & Late Pleistocene	very high to high
Qalc, alluvium in active channels	sand, gravel, & silt	loose	Holocene & Late Pleistocene	very high to high
Qalf, alluvium as fan deposits	sand, gravel, & silt	loose to firm	Holocene & Late Pleistocene	high to moderate
Qc, colluvium	silt, sand, & clay, locally with abundant rock fragments	loose to firm	Holocene & Late Pleistocene	low
Qb, beach deposits	fine- to medium-grained sand, locally with rounded pebble gravel	loose	Holocene & Late Pleistocene	very high
Qd, dunes	fine- to medium-grained sand	loose	Holocene & Late Pleistocene	very high
Qu, alluvium and colluvium, undivided	chiefly alluvium & colluvium, locally includes cultivated residual soils	loose to firm	Holocene & Late Pleistocene	moderate to low
Qts, stream terrace deposits	gravel, sand, & silt	dense	Late Pleistocene	low to very low
Qtn, coastal terrace deposits, nonmarine	gravel, sand, silt, & clay	dense to very dense	Late Pleistocene	very low
Qtny, younger coastal terrace deposits, nonmarine	gravel, sand, silt, & clay	firm to moderately dense	Holocene (?) & Late Pleistocene	low to very low
Qtm, coastal terrace deposits, marine	sand, silty sand, & gravel	dense to very dense	Late Pleistocene	very low

(*when saturated)

Table 1.1. Quaternary Map Units Used in the Point Dume Quadrangle (Campbell and others, 1996) and Their Geotechnical Characteristics and Liquefaction Susceptibility

GROUND-WATER CONDITIONS

Liquefaction hazard may exist in areas where depth to ground water is 40 feet or less. DMG uses the highest known ground-water levels because water levels during an earthquake cannot be anticipated because of the unpredictable fluctuations caused by natural processes and human activities. A historical-high ground-water map differs from most ground-water maps, which show the actual water table at a particular time. Plate 1.2 depicts a hypothetical ground-water table within alluviated areas.

Ground-water conditions were investigated in the Point Dume Quadrangle to evaluate the depth to saturated materials. Saturated conditions reduce the effective normal stress, thereby increasing the likelihood of earthquake-induced liquefaction (Youd, 1973). The evaluation was based on first-encountered water noted in geotechnical borehole logs acquired from the City of Malibu and the Los Angeles County Public Works Department. The depths to first-encountered unconfined ground-water were plotted onto a map of the project area to constrain the estimate of historically shallowest ground water. Water depths from boreholes known to penetrate confined aquifers were not utilized.

We estimated historical-high depth to ground water though a process of applying professional judgement, as constrained by basic principles of ground-water and surface-water hydrology and by a conservative bias. For example, in small stream valleys that drain a correspondingly small area, we anticipate that young alluvial deposits will not be saturated except for the several hours or few days during which these streams are in flood during storm events. On the other hand, stream valleys that drain large areas are more likely to have permanent baseflow within the alluvium even during relatively dry parts of the year. In many areas where ground-water-depth observations were available, we generally rounded those depths up to the next higher five-foot increment. We then classified areas of Quaternary deposits into areas of relatively uniform historical high ground-water level (Plate 1.2).

The only source of data on ground-water depths within the Point Dume Quadrangle was the set of boreholes discussed previously and posted on Plate 1.2. Of the 32 borehole logs acquired, 17 encountered the water table on the date they were drilled. Observed depths to ground water ranged from 5 feet to 34 feet, over a period of time ranging from 8/20/1986 to 9/21/1999. Of the 15 “dry” boreholes, eight had total boring depths of 31 feet or less. The possibility of relatively shallow ground water cannot be ruled out on the basis of these boreholes. Nine ground-water depth observations come from the immediate coastal area (beach, dunes, or lower marine terrace). The rest come from Triunfo Canyon. Of the nine boreholes located on Pleistocene coastal or stream terrace deposits, only one encountered ground water. The rest were dry to their total depths of 50 feet or more.

We estimate historical-high ground-water depth along the beach and dunes to be no greater than five feet. We estimate ground-water depth in the small coastal stream canyons to be approximately 10 feet, with depth increasing in their upper reaches. In the narrow stream valleys throughout most of the interior of the quadrangle (where we have no data), we estimate that historical-high ground-water depths are generally approximately 10 to15 feet and increase in their upper reaches and small side canyons to depths generally in excess of the thickness of alluvium. In Triunfo Canyon and its tributaries, we estimate that historical-high ground-water depth is between five and 10 feet throughout most of the system, but decreases to nearly zero in the vicinity of Malibu Lake.

PART II

LIQUEFACTION HAZARD POTENTIAL

Liquefaction may occur in water-saturated sediment during moderate to great earthquakes. Liquefied sediment loses strength and may fail, causing damage to buildings, bridges, and other structures. Many methods for mapping liquefaction hazard have been proposed. Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of liquefaction susceptibility and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce a liquefaction potential map. Liquefaction susceptibility is a function of the capacity of sediment to resist liquefaction. Liquefaction opportunity is a function of the potential seismic ground shaking intensity.

The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985). Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for their mapping of liquefaction hazards in the Los Angeles region. This method combines geotechnical analyses, geologic and hydrologic mapping, and probabilistic earthquake shaking estimates, but follows criteria adopted by the State Mining and Geology Board (DOC, 2000).

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of a soil to loss of strength when subjected to ground shaking. Physical properties of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance to liquefaction. Some of these properties can be correlated to a sediment's geologic age and environment of deposition. With increasing age, relative density may increase through cementation of the particles or compaction caused by the weight of the overlying sediment. Grain-size characteristics of a soil also influence susceptibility to liquefaction. Sand is more susceptible than silt or gravel, although silt of low plasticity is treated as liquefiable in this investigation. Cohesive soils generally are not considered susceptible to liquefaction. Such soils may be vulnerable to strength loss with remolding and represent a hazard that is not addressed in this investigation. Soil characteristics and processes that result in higher measured penetration resistances generally indicate lower liquefaction susceptibility. Thus, blow count and cone penetrometer values are useful indicators of liquefaction susceptibility.

Saturation is required for liquefaction, and the liquefaction susceptibility of a soil varies with the depth to ground water. Very shallow ground water increases the susceptibility to liquefaction (soil is more likely to liquefy). Soils that lack resistance (susceptible soils) typically are saturated, loose and sandy. Soils resistant to liquefaction include all soil types that are dry, cohesive, or sufficiently dense.

DMG’s map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps and historical occurrences, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, liquefaction susceptibility maps typically are similar to Quaternary geologic maps. DMG’s qualitative relations between susceptibility and geologic map units are summarized in Table 1.1.

LIQUEFACTION OPPORTUNITY

Liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for strong ground shaking. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10% probability of exceedance over a 50-year period (DOC, 2000). The earthquake magnitude used in DMG’s analysis is the magnitude that contributes most to the calculated PGA for an area.

For the Point Dume Quadrangle, PGAs of 0.47 g to 0.55 g, resulting from an earthquake of magnitude 7.3, were used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10% in 50-year hazard level (Petersen and others, 1996; Cramer and Petersen, 1996). See the ground motion section (3) of this report for further details.

Quantitative Liquefaction Analysis

DMG performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; National Research Council, 1985; Seed and others, 1985; Seed and Harder, 1990; Youd and Idriss, 1997). Using the Seed-Idriss Simplified Procedure one can calculate soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR), based on SPT results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The Seed-Idriss Simplified Procedure requires normalizing earthquake loading relative to a M7.5 event for the liquefaction analysis. To accomplish this, DMG's analysis uses the Idriss magnitude scaling factor (MSF) (Youd and Idriss, 1997). It is convenient to think in terms of a factor of safety (FS) relative to liquefaction, where: FS = (CRR / CSR) * MSF. FS, therefore, is a quantitative measure of liquefaction potential. DMG uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site and related structures. The DMG liquefaction analysis program calculates an FS for each geotechnical sample for which blow counts were collected. Typically, multiple samples are collected for each borehole. The lowest FS in each borehole is used for that location. FS values vary in reliability according to the quality of the geotechnical data used in their calculation. FS, as well as other considerations such as slope, presence of free faces, and thickness and depth of potentially liquefiable soil, are evaluated in order to construct liquefaction potential maps, which are then used to make a map showing zones of required investigation.

Of the 32 geotechnical borehole logs reviewed in this study (Plate 1.2), 16 include blow-count data from SPTs or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2½-inch inside-diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all of the information (e.g. soil density, moisture content, sieve analysis, etc.) required for an ideal Seed-Idriss Simplified Procedure. For boreholes having acceptable penetration tests, liquefaction analysis is performed using recorded density, moisture, and sieve test values or using averaged test values of similar materials.

The Seed-Idriss Simplified Procedure for liquefaction evaluation was developed primarily for clean sand and silty sand. As described above, results depend greatly on accurate evaluation of in-situ soil density as measured by the number of soil penetration blow counts using an SPT sampler. However, many of the Holocene alluvial deposits in the study area contain a significant amount of gravel. In the past, gravelly soils were considered not to be susceptible to liquefaction because the high permeability of these soils presumably would allow the dissipation of pore pressures before liquefaction could occur. However, liquefaction in gravelly soils has been observed during earthquakes, and recent laboratory studies have shown that gravelly soils are susceptible to liquefaction (Ishihara, 1985; Harder and Seed, 1986; Budiman and Mohammadi, 1995; Evans and Zhou, 1995; and Sy and others, 1995). SPT-derived density measurements in gravelly soils are unreliable and generally too high. They are likely to lead to overestimation of the density of the soil and, therefore, result in an underestimation of the liquefaction susceptibility. To identify potentially liquefiable units where the N values appear to have been affected by gravel content, correlations were made with boreholes in the same unit where the N values do not appear to have been affected by gravel content.

LIQUEFACTION ZONES

Criteria for Zoning

Areas underlain by materials susceptible to liquefaction during an earthquake were included in liquefaction zones using criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the California State Mining and Geology Board (DOC, 2000). Under those guideline criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historical earthquakes

2. All areas of uncompacted artificial fill containing liquefaction-susceptible material that are saturated, nearly saturated, or may be expected to become saturated

3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable

4. Areas where existing geotechnical data are insufficient

In areas of limited or no geotechnical data, susceptibility zones may be identified by geologic criteria as follows:

a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or

b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historical high water table is less than or equal to 30 feet below the ground surface; or

c) Areas containing soil deposits of latest Pleistocene age (11,000 to 15,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historical high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria to liquefaction zoning in the Point Dume Quadrangle is summarized below.

Areas of Past Liquefaction

In the Point Dume Quadrangle, no areas of documented historical liquefaction are known. Areas showing evidence of paleoseismic liquefaction have not been reported.

Artificial Fills

In the Point Dume Quadrangle, artificial fill areas large enough to show at the scale of mapping consist of engineered fill for river levees and elevated freeways. Since these fills are considered to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata. Non-engineered fills are commonly loose and uncompacted, and the material varies in size and type.

Areas with Sufficient Existing Geotechnical Data

Borehole logs that include penetration test data and sufficiently detailed lithologic descriptions were used to evaluate liquefaction potential. These areas with sufficient geotechnical data were evaluated for zoning based on the liquefaction potential determined by the Seed-Idriss Simplified Procedure. Holocene beach deposits within the quadrangle are well-characterized by several boreholes with acceptable penetration tests, as are alluvial valley deposits present in lower Zuma Canyon and Triunfo Canyon in the vicinity of Malibu Lake. Analysis of borehole logs in these areas using the Seed-Idriss Simplified Procedure indicates that these areas contain sediment layers that may liquefy under the expected earthquake loading. The areas containing saturated potentially liquefiable material with corresponding depths as shown in Table 1.1 are included in the zone.

Areas with Insufficient Existing Geotechnical Data

Younger alluvium deposited in stream channel areas generally lacks adequate geotechnical borehole information. The soil characteristics and ground-water conditions in these deposits are assumed to be similar to deposits where subsurface information is available. For example, although a borehole log in lower Trancas Canyon reports unacceptable blow-count data, the log reveals saturated sandy alluvium similar in character to alluvium within Zuma Canyon, where borehole logs do document low SPT results. Such alluvial deposits, therefore, are included in the liquefaction zone for reasons presented in criterion 4a above.

ACKNOWLEDGMENTS

The author thanks Christopher Dean, Jeffrey Wilson and other staff and managers of the City of Malibu for being particularly helpful in our acquisition of their borehole data and a digital parcel boundary map of the City of Malibu. Thanks also go to the helpful staff of the Los Angeles County Public Works Department for providing additional geotechnical data that were critical for the completion of this study.

REFERENCES

American Society for Testing and Materials, 1999, Standard test method for penetration test and split-barrel sampling of soils, Test Method D1586-99, *in* Annual Book of ASTM Standards, v. 4.08.

Birkeland, P.W., 1972, Late Quaternary eustatic sea-level changes along the Malibu coast, Los Angeles County, California: Journal of Geology, v. 80, no. 4, p. 432-448.

Budiman, J.S. and Mohammadi, Jamshid, 1995, Effect of large inclusions on liquefaction of sands, *in* Evans, M.D. and Fragaszy, R.J., *editors*, Static and Dynamic properties of Gravelly Soils: American Society of Civil Engineers Geotechnical Special Publication no. 56, p. 48-63.

California Department of Conservation, Division of Mines and Geology, 1997, Guidelines for evaluating and mitigating seismic hazards in California, Special Publication 117, 74 p.

California Department of Conservation, Division of Mines and Geology, 2000, Recommended criteria for delineating seismic hazard zones in California, Special Publication 118, 12 p.

Campbell, R.H., Blackerby, B.A., Yerkes, R.F., Schoellhamer, J.E., Birkeland, P.W. and Wentworth, C.M., 1996, Geologic map of the Point Dume Quadrangle, Los Angeles County, California: U.S. Geological Survey Geological Quadrangle Map GQ-1747, 1:24,000.

Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange, and Ventura counties, California: Bulletin of Seismological Society of America, v. 86, no. 5, p. 1,645-1,649.

Evans, M.D. and Zhou, Shengping, 1995, Liquefaction behaviour of sand-gravel composites: American Society of Civil Engineers, Journal of Geotechnical Engineering, v. 121, no. 3, p. 287-298.

Harder, L.F. and Seed, H.B., 1986, Determination of penetration resistance for coarse-grained soils using the Becker hammer drill: University of California at Berkeley, College of Engineering, Earthquake Engineering Research Center, report no. UCB/EERC-86/06, 126 p.

Ishihara, Kenji, 1985, Stability of natural deposits during earthquakes, *in* Proceedings of the Eleventh International Conference on Soil Mechanics and Foundation Engineering, San Francisco, v. 1, p. 321-376.

National Research Council, 1985, Liquefaction of soils during earthquakes: National Research Council Special Publication, Committee on Earthquake Engineering, National Academy Press, Washington, D.C., 240 p.

Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao. T., Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology, Open File Report 96-08; U.S. Geological Survey Open File Report 96-706, 33 p.

Seed, H.B. and Idriss, I.M., 1971, Simplified procedure for evaluating soil liquefaction potential: Journal of the Soil Mechanics and Foundations Division of ASCE, v. 97: SM9, p. 1,249-1,273.

Seed, H.B. and Idriss, I.M., 1982, Ground motions and soil liquefaction during earthquakes: Monograph Series, Earthquake Engineering Research Institute, Berkeley, California, 134 p.

Seed, H.B., Idriss, I.M. and Arango, Ignacio, 1983, Evaluation of liquefaction potential using field performance data: Journal of Geotechnical Engineering, v. 109, no. 3, p. 458-482.

Seed, H.B., Tokimatsu, Kohji, Harder, L.F., and Chung, R.M., 1985, Influence of SPT procedures in soil liquefaction resistance evaluations: Journal of Geotechnical Engineering, ASCE, v. 111, no. 12, p. 1,425-1,445.

Seed, R.B. and Harder, L.F., 1990, SPT-based analysis of cyclic pore pressure generation and undrained residual strength: Proceedings of the H. Bolton Seed Memorial Symposium, v. 2, p. 351-376.

Smith, T.C., 1996, Preliminary maps of seismic hazard zones and draft guidelines for evaluating and mitigating seismic hazards: California Geology, v. 49, no. 6, p. 147-150.

Sy, Alex, Campanella, R.G. and Stewart, R.A., 1995, BPT-SPT correlations for evaluations of liquefaction resistance in gravelly soils, *in* Evans, M.D. and Fragaszy, R.J., *editors*, Static and Dynamic Properties of Gravelly Soils: American Society of Civil Engineers Geotechnical Special Publication no. 56, p. 1-19.

Tinsley, J.C., Youd, T.L., Perkins, D.M. and Chen, A.T.F., 1985, Evaluating liquefaction potential, *in* Ziony, J.I., *editor*, Evaluating earthquake hazards in the Los Angeles region -- An earth science perspective: U.S. Geological Survey Professional Paper 1360, p. 263-316.

Youd, T.L., 1973, Liquefaction, flow and associated ground failure: U.S. Geological Survey Circular 688, 12 p.

Youd, T.L., 1991, Mapping of earthquake-induced liquefaction for seismic zonation: Earthquake Engineering Research Institute, Proceedings, Fourth International Conference on Seismic Zonation, v. 1, p. 111-138.

Youd, T.L. and Idriss, I.M., 1997, *editors*, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: National Center for Earthquake Engineering Research Technical Report NCEER-97-0022, 276 p.

Youd, T.L. and Perkins, D.M., 1978, Mapping liquefaction-induced ground failure potential: Journal of Geotechnical Engineering, v. 104, p. 433-446.

SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Point Dume 7.5-Minute Quadrangle, Los Angeles and Ventura Counties, California

By
Michael A. Silva and Pamela J. Irvine

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps prepared by DMG in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at http://www.consrv.ca.gov/pubs/sp/117/).

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Point Dume 7.5-minute Quadrangle. This section, along with Section 1 (addressing liquefaction), and Section 3 (addressing earthquake shaking), form a report that is one of a series that summarize the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet web page: http://www.consrv.ca.gov/dmg/shezp/.

BACKGROUND

Landslides triggered by earthquakes historically have been a significant cause of earthquake damage. In California, large earthquakes such as the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes triggered landslides that were responsible for destroying or damaging numerous structures, blocking major transportation corridors, and damaging life-line infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, areas underlain by loose, weak soils, and areas on or adjacent to existing landslide deposits. These geologic and terrain conditions exist in many parts of California, including numerous hillside areas that have already been developed or are likely to be developed in the future. The opportunity for strong earthquake ground shaking is high in many parts of California because of the presence of numerous active faults. The combination of these factors constitutes a significant seismic hazard throughout much of California, including the hillside areas of the Point Dume Quadrangle.

METHODS SUMMARY

The mapping of earthquake-induced landslide hazard zones presented in this report is based on the best available terrain, geologic, geotechnical, and seismological data. If unavailable or significantly outdated, new forms of these data were compiled or generated specifically for this project. The following were collected or generated for this evaluation:

- Digital terrain data were used to provide an up-to-date representation of slope gradient and slope aspect in the study area

- Geologic mapping was used to provide an accurate representation of the spatial distribution of geologic materials in the study area. In addition, a map of existing landslides, whether triggered by earthquakes or not, was prepared

- Geotechnical laboratory test data were collected and statistically analyzed to quantitatively characterize the strength properties and dynamic slope stability of geologic materials in the study area

- Seismological data in the form of DMG probabilistic shaking maps and catalogs of strong-motion records were used to characterize future earthquake shaking within the mapped area

The data collected for this evaluation were processed into a series of GIS layers using commercially available software. A slope stability analysis was performed using the

Newmark method of analysis (Newmark, 1965), resulting in a map of landslide hazard potential. The earthquake-induced landslide hazard zone was derived from the landslide hazard potential map according to criteria developed in a DMG pilot study (McCrink and Real, 1996) and adopted by the State Mining and Geology Board (DOC, 2000).

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered from a variety of outside sources. Although the selection of data used in this evaluation was rigorous, the quality of the data is variable. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Due to limitations in methodology, it should be noted that these zone maps do not necessarily capture all potential earthquake-induced landslide hazards. Earthquake-induced ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. It should also be noted that no attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Point Dume Quadrangle, for more information on the delineation of liquefaction zones.

The remainder of this report describes in more detail the mapping data and processes used to prepare the earthquake-induced landslide zone map for the Point Dume Quadrangle. The information is presented in two parts. Part I covers physiographic, geologic and engineering geologic conditions in the study area. Part II covers the preparation of landslide hazard potential and landslide zone maps.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The onshore portion of the Point Dume Quadrangle covers an area of approximately 50 square miles in southwestern Los Angeles County and southeastern Ventura County and includes parts of the cities of Malibu and Westlake Village and the unincorporated communities of Malibu Lake and Cornell. Point Dume is located at the southern boundary of the map area, about 35 miles west of the Los Angeles Civic Center and 10 miles west of the Malibu Civic Center.

The Point Dume Quadrangle is dominated by steep and rugged terrain of the west-central Santa Monica Mountains. Local elevations range from sea level on the south to 2824 feet at Castro Peak in the northeastern quarter of the map. The main crest of the mountain range trends west-northwest across the northern part of the quadrangle. Numerous south-trending ridges with steep-sided canyons extend from the range crest toward the coast. The coastal area is characterized by broad, gently sloping, relatively continuous terrace surfaces that terminate in steep bluffs above narrow to moderately wide beaches.

The most important drainage system in the northern part of the quadrangle includes Triunfo Canyon and its tributaries Lobo Canyon, La Sierra Canyon, and Medea Creek. Lobo and La Sierra canyons drain northeastward into Triunfo Canyon. Medea Creek flows south into Triunfo Canyon via Malibu Lake at the eastern edge of the map. Drainage from Triunfo Canyon flows southeastward from Malibu Lake into Malibu Creek, which flows through the Santa Monica Mountains in the adjacent Malibu Beach Quadrangle to Santa Monica Bay. Major drainages in the southern part of the quadrangle include Trancas, Zuma (Dume), Ramirez (Ramera), Escondido, Latigo, and Solstice canyons, which drain south from the range crest into the Pacific Ocean.

Major east-west transportation routes in the area include State Highway 1 (Pacific Coast Highway) on the south, Mulholland Highway on the north, and U.S. Highway 101, which is located just north of the quadrangle. Kanan-Dume Road traverses the center of the quadrangle and serves as the main north-south artery between Highway 101 and Highway 1. Other north-south access roads include State Highway 23 (Decker Road/Westlake Boulevard) and Encinal Canyon Road on the west and Latigo Canyon Road on the east. Access to undeveloped areas is provided by fire roads and trails.

Residential development is primarily concentrated along Escondido and Trancas beaches and on the coastal bluffs, terraces, and hillsides within the City of Malibu, which was incorporated in 1991. Small residential communities are also present in the unincorporated county area along and adjacent to county roads, including the area between Latigo Canyon and Kanan-Dume Road, and in the Malibu Lake, Cornell, and Seminole Hot Springs areas. Other development in the area includes several privately owned and operated recreation sites, county probation camps, and minor light commercial and agricultural/ranching activity. The majority of the undeveloped land in the Point Dume Quadrangle is parkland managed by the National Park Service, California State Parks, Santa Monica Mountains Conservancy, and Los Angeles County.

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. An accurate slope gradient calculation begins with an up-to-date map representation of the earth's surface. Within the Point Dume Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, which was prepared from the 7.5-minute quadrangle topographic contours that are based on 1947 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

Areas that have undergone large-scale grading since 1947 in the hilly portions of the quadrangle were updated to reflect the new topography. A DEM reflecting this recent grading was obtained from an airborne interferometric radar platform flown in 1998, with an estimated vertical accuracy of approximately 2 meters (Intermap Corporation, 2000). An interferometric radar DEM is prone to creating false topography where tall buildings, metal structures, or trees are present. The final hazard zone map was checked for potential errors of this sort and corrected. Graded areas where the radar DEM was applied are shown on Plate 2.1.

A slope map was made from both DEMs using a third-order, finite difference, center-weighted algorithm (Horn, 1981). The USGS DEM was also used to make a slope aspect map. The manner in which the slope and aspect maps were used to prepare the zone map will be described in subsequent sections of this report.

GEOLOGY

Bedrock and Surficial Geology

The primary source of bedrock geologic mapping used in this slope stability evaluation was obtained from the U.S. Geological Survey (Campbell and others, 1996) and then digitized by Southern California Areal Mapping Project (SCAMP) staff. This source was also used for the surficial geologic mapping for the Point Dume Quadrangle because the quadrangle contains relatively small areas of young surficial deposits. Surficial geology is discussed in detail in Section 1 of this report.

The digitized geologic map was modified by DMG geologists in the following ways. Landslide deposits were deleted from the map so that the distribution of bedrock formations and the landslide inventory would exist on separate layers for the hazard analysis. Contacts between bedrock and surficial units were revised to better conform to the topographic contours of the U.S.G.S. 7.5-minute quadrangle. Bedrock geology was modified in some areas to reflect more recent mapping. Air-photo interpretation and field reconnaissance were performed to assist in adjusting contacts between bedrock and surficial geologic units, to review lithology of geologic units and geologic structure, and to note the relationship of the various geologic units to the development and abundance of slope failures.

Yerkes and Campbell (1979) revised the stratigraphic nomenclature of the central Santa Monica Mountains based on detailed mapping of the unincorporated Los Angeles County portions of the Santa Monica Mountains (Yerkes and others, 1971). They concluded that the Malibu Coast Fault represents the boundary between two different geologic terranes. On the north side of the fault, a basement of Santa Monica Slate and granodiorite is overlain by Upper Cretaceous through upper Miocene rocks and, on the south, a basement of Catalina Schist is overlain by Miocene and younger rocks.

The oldest geologic unit mapped in the Point Dume Quadrangle is the Late Cretaceous Tuna Canyon Formation (Kt), which crops out in upper Solstice Canyon in the east-central part of the map area and between Trancas and Zuma canyons in the southwest. It consists of massive, coarse-grained, thick-bedded marine sandstone and pebbly sandstone interbedded with thin-bedded siltstone representing deposition in a submarine delta-fan complex. In upper Solstice Canyon, the Tuna Canyon Formation is discomformably overlain by the lower Paleocene Simi Conglomerate (Tsi), which is composed of nonmarine quartzite cobble conglomerate, coarse-grained arkosic sandstone, and a distinctive pisolitic paleosol horizon. Elsewhere, the Tuna Canyon Formation is overlain by Paleocene and Eocene very fine- to fine-grained, semi-friable to hard, thick-bedded marine sandstone, resistant pebble conglomerate, and conchoidally fractured siltstone of the Coal Canyon Formation (Tcc). The middle Eocene Llajas Formation (Tll) conformably overlies the Coal Canyon Formation in upper Solstice Canyon and Trancas Canyon and is composed of very fine-grained, micaceous marine sandstone and siltstone with minor pebble conglomerate.

Overlying the Upper Cretaceous through middle Eocene strata is a sequence of laterally gradational and interfingering nonmarine, transitional, and marine clastic sedimentary rocks assigned to the Sespe, Vaqueros, and Topanga Canyon formations by Yerkes and Campbell (1979). This sequence records deposition during several shoreline transgressions and regressions in late Oligocene to early Tertiary time (Fritsche, 1993). Forming the base of this sequence is the upper Eocene to lower Miocene Sespe Formation (Ts), which crops out in uppermost Solstice Canyon and between Zuma and Trancas canyons. It consists of alluvial-fan and floodplain deposits of pebble-cobble conglomerate and massive to thick-bedded sandstone interbedded with thin-bedded siltstone and mudstone. The Sespe Formation is conformably overlain by and locally intertongues with the upper Oligocene to lower Miocene Vaqueros Formation (Tv), which consists of nonmarine, deltaic, and marine strandline deposits of medium- to coarse-grained, thin- to thick-bedded biotitic sandstone interbedded with siltstone and mudstone, and minor pebbly sandstone. The Vaqueros Formaion is exposed as a narrow band extending across the map from Castro Crest in the northeast to Encinal Canyon in the southwest.

The Vaqueros Formation is conformably overlain by thick-bedded marine sandstone of the undivided Topanga Canyon Formation (Ttc) in the eastern part of the area and by marine siltstone and silty mudstone of the Encinal Member (Ttce) of the Topanga Canyon Formation in the west. The lower to middle Miocene Topanga Canyon Formation represents the lowest division of the Topanga Group (Yerkes and Campbell, 1979).

Overlying the intertonguing marine and nonmarine upper Oligocene to middle Miocene strata are the middle Miocene Conejo Volcanics and Calabasas Formation, which constitute the middle and upper parts of the Topanga Group. The Conejo Volcanics were erupted into a structurally controlled marine basin from an ancient oceanic volcano complex that eventually emerged to form a land mass as lava flows accumulated and filled the basin (Williams, 1977). In the northern part of the quadrangle, the Conejo Volcanics are divided into two rock units, an andesitic and basaltic breccia (Tcob), which includes pillow breccia, mudflow breccia, and a basal sandstone and mudstone, and another unit that primarily consists of andesitic and basaltic flows (Tcof). In the east-central and south-central map area, two stratigraphically distinct tongues of Conejo Volcanics are interbedded with Calabasas Formation strata. The Ramera Canyon Tongue (Tcor) consists of andesitic and basaltic breccia, tuff breccia, flows, and minor volcanic sandstone and is overlain by the Dry Canyon Sandstone Member of the Calabasas Formation. The Solstice Canyon Tongue (Tcos) is composed of basaltic and andesitic flows, breccia, tuff, and volcanic sandstone. It is underlain by the Latigo Canyon Breccia and Escondido Canyon Shale members of the Calabasas Formation and is overlain by and intertongues with the Dry Canyon Sandstone Member of the Calabasas Formation. Intrusive rocks (Ti) consist of basaltic and diabasic (Tib) and andesitic (Tia) dikes, sills, and irregular bodies that intrude both the older sedimentary rock units and other units within the Conejo Volcanics.

The Calabasas Formation consists of a sequence of marine sandstone, siltstone, and sedimentary breccia that intertongues with and overlies the Conejo Volcanics. Yerkes and Campbell (1979) divided the formation into several members. The Escondido Canyon Shale Member (Tce) is widely exposed in the east-central and southeast parts of the quadrangle and consists of marine siltstone, mudstone with dolomitic concretions, shale, and thin interbedded sandstone turbidites. The Latigo Canyon Breccia Member (Tcl) is composed of lenticular beds of sedimentary breccia that contain angular blocks of sandstone derived from the Sespe and Vaqueros formations and clasts of volcanic rock in an unsorted matrix of sand, silt, and minor clay. It is interpreted to represent one or more large submarine landslide deposits. The Dry Canyon Sandstone Member (Tcd), which crops out in the southeast part of the map area, is composed of sandstone and interbedded siltstone representing turbidite deposition in a submarine fan environment. Undivided Calabasas Formation (Tc), consisting of sandstone and interbedded siltstone, is exposed as small, discontinuous outcrops in the east-central part of the map area.

Some of the exposures near the northeast corner and central area of the quadrangle that were mapped as Calabasas Formation by Campbell and others (1996) are included in the upper Miocene Modelo Formation (Tmo) in this study because of lithologic similarities with Modelo Formation strata in adjacent areas. In the map area, the Modelo Formation is composed of thin-bedded, platy siliceous shale and clay shale with minor interbedded sandstone and siltstone.

The sequence of bedrock units south of the Malibu Coast Fault, which Yerkes and Campbell (1979) mapped as a separate geologic terrane, consists of the lower to middle Miocene Zuma Volcanics and Trancas Formation and the middle to upper Miocene Monterey Formation. The Zuma Volcanics (Tz) is exposed in the south-central and southeastern part of the map and consists of basaltic and andesitic flows, flow breccia, pillow lava, aquagene tuff, mudflow breccia, volcanic sandstone and interbedded marine mudstone, siltstone, and sandstone. The Zuma Volcanics is overlain by and intertongues with the Trancas Formation (Tr), which is best exposed in the southeastern part of the map area and occurs as smaller, discontinuous outcrops in the southwest. The Trancas Formation is primarily composed of marine sandstone, mudstone, silty shale, claystone, and conglomerate. A distinctive sedimentary breccia unit containing abundant clasts of

Catalina Schist crops out at Lechusa Point. This unit has been mapped by many geologists as the San Onofre Breccia (Campbell and others, 1996, Dibblee and Ehrenspeck, 1993, Fritsche and others, 2001).

In the Point Dume Quadrangle, Campbell and others (1996) mapped two units within the Monterey Formation. The upper Miocene Monterey Shale (Tm) locally intertongues with and overlies the Trancas Formation and is composed of marine clay shale, laminated to platy siltstone, and interbedded altered vitric tuffs and minor fine- to medium-grained sandstone. It is exposed in the southern part of the map area along the drainages cut in the terrace surface near Point Dume. The other unit (Tmd) mapped within the Monterey Formation is a middle Miocene sequence of intensely deformed shale, siltstone, and very fine grained sandstone that is exposed in the south-central and southeastern areas along major thrust faults.

The Monterey Formation and older bedrock units are unconformably overlain by upper Pleistocene marine (Qtm) and nonmarine (Qtn) coastal terrace deposits in the southern part of the quadrangle. Scattered remnants of upper Pleistocene stream-terrace deposits (Qts) are present along the flanks of the larger canyons and valleys in the map area.

Other Quaternary surficial deposits in the Point Dume Quadrangle consist of upper Pleistocene to Holocene nonmarine coastal terrace deposits (Qtyn), undifferentiated surficial deposits (Qu), fan deposits (Qalf), landslide deposits (Qls), dunes (Qd), beach deposits (Qb), colluvium (Qc), undifferentiated alluvial deposits (Qal), alluvial floodplain deposits (Qalp), alluvium in active channels (Qalc), and artificial fill (af). Landslides and landslide deposits are not shown on the bedrock/Quaternary geology map, but are included on a separate landslide inventory map (Plate 2.1). A detailed discussion of Quaternary units in the Point Dume Quadrangle can be found in Section 1.

Structural Geology

The Point Dume Quadrangle is located in the west-central Santa Monica Mountains near the southern boundary of the Transverse Ranges Province. Rocks in the Point Dume Quadrangle have been complexly folded and faulted during several periods of deformation. The resulting structural complexity is further complicated by the presence of igneous intrusives injected along the faults and the intertonguing relationships within many of the sedimentary and volcanic rock units, making mapping and interpretation of the structural geology in this area both difficult and controversial (Campbell and others, 1966).

The structural geology of the Point Dume Quadrangle is characterized by a north-dipping homocline of middle Miocene and older strata, which was subsequently cut by high-angle faults, overlain by detachment sheets, and then folded and subjected to north-over-south thrusting along its southern margin (Campbell and others, 1996). The tilting, high-angle faulting, and emplacement of detachment sheets occurred as a result of crustal block rotation and extension, which was accompanied by volcanism, during middle to late middle Miocene time.

Campbell and others (1966; 1996) postulate that detachment faulting in the Point Dume Quadrangle divided the middle Miocene and older strata into three structural units: an autochthon(?) of Cretaceous and Paleocene sedimentary rock and older basement rock overlain by two superimposed detachment thrust sheets. These detachment thrust sheets, named Zuma and Malibu Bowl in ascending order, were emplaced by gravity tectonics from north to south along the Zuma and Malibu Bowl faults in latest middle Miocene time. The autochthon is exposed in Zuma and Trancas canyons in windows through the Malibu Bowl and Zuma thrust sheets. The Zuma thrust sheet extends across the center of the quadrangle and contains rocks of the Sespe and Vaqueros formations. The Zuma thrust sheet was cut by northeast-trending high-angle faults and gently folded prior to emplacement of the overlying Malibu thrust sheet. The Malibu Bowl thrust sheet consists of intertonguing Conejo Volcanics and Calabasas Formation strata and is exposed in the east-central part of the map area. The thrust-sheet contacts, seen only in rare exposures, are parallel or nearly parallel to bedding and are characterized by zones of brecciation and, along the Zuma thrust sheet, igneous intrusion.

The gravity detachment fault theory has not been accepted by all geologists (Truex, 1976, 1977; Dibblee, 1993; and Dibblee and Ehrenspeck, 1993). Dibblee and Ehrenspeck (1993) noted that, while there is some evidence for thrust faulting in the area, they believe that some of the detachment fault contacts mapped by Campbell and others (1966 and 1996) and Yerkes and Campbell (1980) may instead represent buttress angular unconformities. Fritsche and others (2001) postulate that the detachment sheets represent gravity slides off the slope of a Conejo volcano similar to the slides that have occurred in Hawaii rather than regional detachment faults.

The structures described above are truncated on the south by the Malibu Coast Fault Zone, an east-west-trending, north-dipping reverse fault zone that has also had significant left-lateral displacement (Treiman, 1994). The Malibu Coast Fault Zone is part of a larger left-lateral, reverse-oblique fault system that forms the southern boundary of the Transverse Ranges Province. Significant left-lateral movement is believed to have occurred on this fault system in the Miocene during clockwise rotation of crustal blocks within the Transverse Ranges (Hornafius and others, 1986). Between the late Miocene and Pliocene, the sense of displacement on the Malibu Coast Fault changed from one of lateral or extensional to one of north-over-south thrusting as the local tectonic regime became dominated by north-south compression (Campbell and others, 1996). Thrust faulting was accompanied by uplift of the Santa Monica Mountains relative to the offshore Santa Monica basin.

In the Point Dume Quadrangle, the Malibu Coast Fault Zone consists of two main strands, a northern strand mapped by Campbell and others (1996) and a southern strand mapped by Dibblee and Ehrenspeck (1993). The trace of the fault strands coincide west of Trancas Canyon but are separated by as much as ¾ mile between Trancas and Ramirez canyons. The zone becomes more complex between Ramirez and Escondido canyons and Solstice Canyon in the east where additional faults splay from the main strands. Another significant fault in the area is the Escondido Thrust, a nearly flat-lying to north-dipping, south-verging thrust fault that extends from Trancas Canyon east to Escondido

Canyon (Treiman, 1994). Quaternary faulting and associated folding have locally deformed and weakened rocks in a zone up to one mile wide along the coast.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Point Dume Quadrangle was prepared by field reconnaissance, analysis of stereo-paired aerial photographs and a review of previously published and unpublished landslide mapping. The landslide maps and reports that were reviewed during preparation of the landslide inventory are identified in the References section with an asterisk (*). Landslides were mapped and digitized at a scale of 1:24,000. For each landslide included on the map a number of characteristics (attributes) were compiled. These characteristics include the confidence of interpretation (definite, probable and questionable) and other properties, such as activity, thickness, and associated geologic unit(s). Landslides rated as definite and probable were carried into the slope stability analysis. Landslides rated as questionable were not carried into the slope stability analysis due to the uncertainty of their existence. The completed hand-drawn landslide map was scanned, digitized, and the attributes were compiled in a database. A version of this landslide inventory is included with Plate 2.1.

In general, landslides are abundant in the southern two thirds of the Point Dume Quadrangle where the sedimentary rocks have been deformed by several episodes of folding and faulting. Relatively few landslides exist in the less deformed volcanic terrain in the northern part of the map. Landslides in the area range from minor surficial failures resulting from soil and rock creep, rock fall, soil and debris slumps, and debris flows to large rotational and translation landslides, some of which are relatively old and deeply eroded. Landslide identification in the Point Dume Quadrangle is difficult due to the structural complexity of the area and the presence of coastal terraces that can be mistaken for landslide morphology.

Rock falls, rock slides, and debris avalanches involving jointed and fractured bedrock of the Sespe and Vaqueros formations and volcanic breccias occur on the steeper slopes within the mountain range. Debris flows are common on moderate to steep slopes. Individual debris-flow tracks and deposits were not mapped for this study.

Rotational rock and debris slides are the most common types of slides in the area. Slides involving bedrock (Tr and Tmd), terrace deposits, and artificial fill occur along the coastal terrace bluffs at Latigo Point and Escondido Beach . Numerous slides have occurred in the crumbly shale and friable sandstone of the Trancas Formation in the southeast. Rotational and translational rock and debris slides are also common along the south-trending canyons south of the range crest, especially in the vicinity of faults and folds. Numerous large, ancient landslides have been mapped in Sespe, Vaqueros, and Escondido Canyon Shale strata in the south-central part of the quadrangle. Many of the recently active slides occur within these older, previously identified landslides.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units were ranked on the basis of their shear strength. Shear strength data for rock units identified on the geologic map were obtained from the City of Malibu and Los Angeles County (Appendix A). The locations of rock and soil samples taken for shear testing are shown on Plate 2.1. Shear tests from the adjacent Malibu Quadrangle were used to augment data for several geologic formations that had little shear test information available in the Point Dume Quadrangle.

Shear strength data gathered from the above sources were compiled for each geologic map unit. Geologic units were grouped on the basis of average angle of internal friction (average phi) and lithologic character. Average (mean and median) phi values for each geologic unit are summarized in Table 2.1. Within the Point Dume Quadrangle, no shear tests were available for Kt, Qalf, Qb, Qc, Qd, Qtn, Qtny, Qts, Qu, Tia, Tib, Tc, Tcd, Tcl, Tcor, Tcs, Tmo, Ts, Tsi, and Ttc. No shear tests for these units were found in adjacent quadrangles. Shear tests from the Malibu Quadrangle were used to augment values for af, Qa, Qls, Qtm, Tcc, Tcos, Ti, Tm and Tv. Units with no shear tests were added to existing groups on the basis of lithologic and stratigraphic similarities. A geologic material strength map was made based on the groupings presented in Tables 2.1 and 2.2. The geologic material strength map provides a spatial representation of material strength for use in the slope stability analysis.

One map unit, the Vaqueros Formation (Tv) was subdivided further, as discussed below.

Adverse Bedding Conditions

Adverse bedding conditions are an important consideration in slope stability analyses. Adverse bedding conditions occur where the dip direction of bedded sedimentary rocks is roughly the same as the slope aspect, and where the dip magnitude is less than the slope gradient. Under these conditions, landslides can slip along bedding surfaces due to a lack of lateral support.

To account for adverse bedding in our slope stability evaluation, we used geologic structural data in combination with digital terrain data to identify areas with potentially adverse bedding, using methods similar to those of Brabb (1983). The structural data, derived from the geologic map database, was used to categorize areas of common bedding dip direction and magnitude. The dip direction was then compared to the slope aspect and, if the same, the dip magnitude and slope gradient categories were compared. If the dip magnitude was less than or equal to the slope gradient category but greater than 25% (4:1 slope), the area was marked as a potential adverse bedding area.

The Vaqueros Formation (Tv), which contains interbedded sandstone, siltstone and mudstone, was subdivided based on shear strength differences between coarse-grained (higher strength) and fine-grained (lower strength) lithologies. Shear strength values for the fine- and coarse-grained strengths were then applied to areas of favorable and adverse bedding orientation, which were determined from structural and terrain data as discussed above. It was assumed that coarse-grained material strength dominates where bedding dips into a slope (favorable bedding) while fine-grained material strength dominates where bedding dips out of a slope (adverse bedding). The geologic material strength map was modified by assigning the lower, fine-grained shear strength value to areas where adverse bedding was identified. The favorable and adverse bedding shear strength parameters for the Vaqueros Formation are included in Table 2.1.

Existing Landslides

The strength characteristics of existing landslides (Qls) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount information is rarely available, and for the preparation of the earthquake-induced landslide zone map it has been assumed that all landslides within the quadrangle have the same slip surface strength parameters. We collect and use primarily “residual” strength parameters from laboratory tests of slip surface materials tested in direct shear or ring shear test equipment. Back-calculated strength parameters, if the calculations appear to have been performed appropriately, have also been used. For the Point Dume Quadrangle, 14 direct shear tests of landslide slip surface materials obtained from the Malibu Beach Quadrangle were used, and the results are summarized in Table 2.1.

POINT DUME QUADRANGLE SHEAR STRENGTH GROUPS

	Formation Name	Numbe r of Tests	Mean/Median Phi (degrees)	Mean/Median Group Phi (degrees)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analysis
GROUP 1	Tcc	21	37	35/36	529/404	Kt	35
	Tcob	4	33/35			Tcor	
	Tcof	2	39			Tia	
	Tcos	8	34			Tib	
	Tcosr	2	36			Tsi	
	Ti	12	34/36			Ttc	
	Tll	2	37				
	Tv(fbc)	24	34				
	Tz	28	36				
GROUP 2	Tm	58	33	32	482/381	Tcl	32
	Tmd	56	31/32			Tmo	
	Tr	21	31			Ts	
GROUP 3	af	24	28	28	427/350	Qalf, Qb	28
	Qa	4	31/27			Qc, Qd	
	Qtm	24	27/28			Qtn, Qtny	
	Tce	67	30/29			Qts, Qu	
	Ttce	14	26/28			Tc, Tcd	
	Tv(abc)	17	28/30			Tcs	
GROUP 4	Qls	14	17/16	17/16	410/395		16
	fbc = Favorable bedding conditions						
	abc = Adverse bedding conditions						
	Formations for strength groups from Campbell and others, 1996						

Table 2.1. Summary of the Shear Strength Statistics for the Point Dume Quadrangle.

SHEAR STRENGTH GROUPS FOR THE POINT DUME 7.5-MINUTE QUADRANGLE			
GROUP 1	**GROUP 2**	**GROUP 3**	**GROUP 4**
Kt	Tcl	af	Qls
Tcc	Tm	Qa	
Tcob	Tmd	Qalf	
Tcof	Tmo	Qb	
Tcor	Tr	Qc	
Tcos	Ts	Qd	
Tcosr		Qtm	
Ti		Qtn	
Tia		Qtny	
Tib		Qts	
Tll		Qu	
Tsi		Tc	
Ttc		Tcd	
Tv(fbc)		Tce	
Tz		Tcs	
		Ttce	
		Tv(abc)	
fbc = favorable bedding conditions			
abc = adverse bedding conditions			

Table 2.2. Summary of Shear Strength Groups for the Point Dume Quadrangle.

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

To evaluate earthquake-induced landslide hazard potential in the study area, a method of dynamic slope stability analysis developed by Newmark (1965) was used. The Newmark method analyzes dynamic slope stability by calculating the cumulative down-slope displacement for a given earthquake strong-motion time history. As implemented for the preparation of earthquake-induced landslide zones, the Newmark method necessitates the selection of a design earthquake strong-motion record to provide the “ground shaking opportunity”. For the Camarillo Quadrangle, selection of a strong motion record was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by DMG for a 10% probability of being exceeded in 50 years (Petersen and others, 1996). The parameters used in the record selection are:

Modal Magnitude:	7.2 to 7.3
Modal Distance:	2.5 to 5.1 km
PGA:	0.44g to 0.57g

The strong-motion record selected for the slope stability analysis in the Newbury Park Quadrangle was the Southern California Edison (SCE) Lucerne record from the 1992 magnitude 7.3 Landers, California, earthquake. This record had a source to recording site distance of 1.1 km and a peak ground acceleration (PGA) of 0.80g. Although the distance and PGA values of the Lucerne record do not fall within the range of the probabilistic parameters, this record was considered to be sufficiently conservative to be used in the stability analyses. The selected strong-motion record was not scaled or otherwise modified prior to its use in the analysis.

Displacement Calculation

The design strong-motion record was used to develop a relationship between landslide displacement and yield acceleration (a_y), defined as the earthquake horizontal ground acceleration above which landslide displacements take place. This relationship was prepared by integrating the design strong-motion record twice for a given acceleration value to find the corresponding displacement, and the process was repeated for a range of acceleration values (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for the design strong-motion record. This curve provides the required link between anticipated earthquake shaking and estimates of displacement for different combinations of geologic materials and slope gradient, as described in the Slope Stability Analysis section below.

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm are used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and the DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.142, 0.182, and 0.243 g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant to the Point Dume Quadrangle.

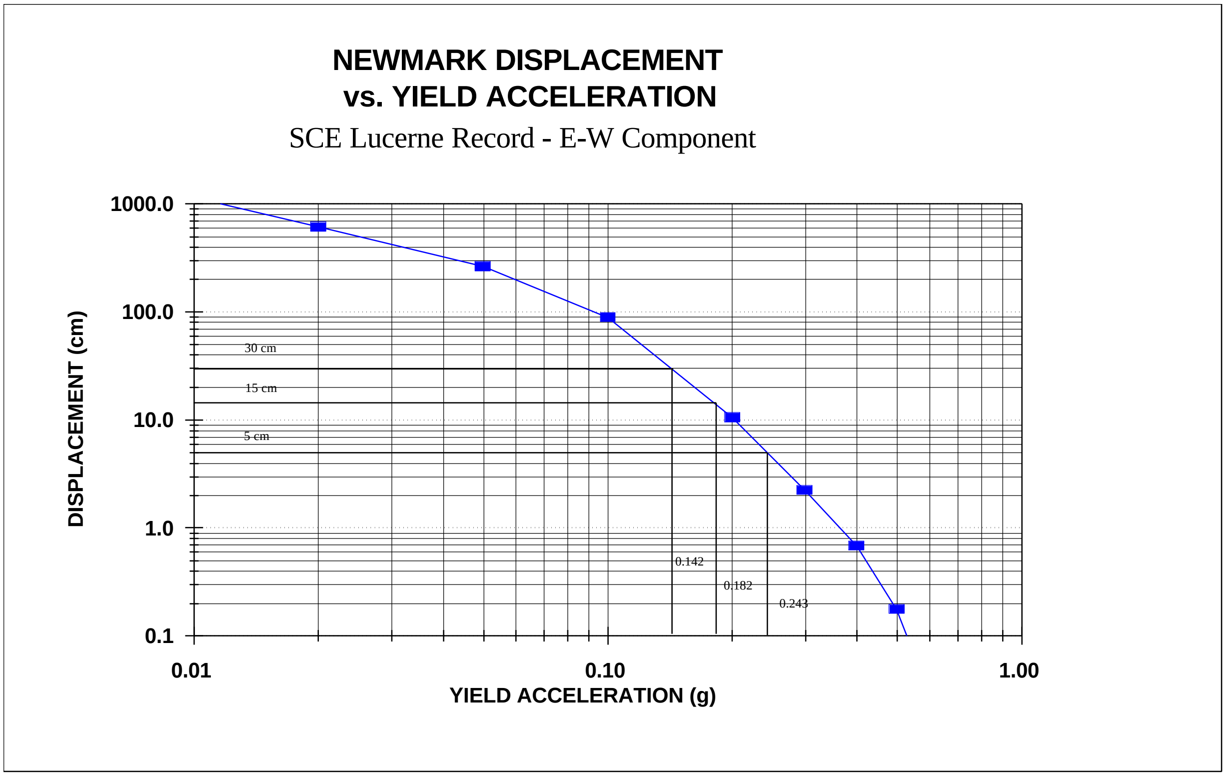


Figure 2.1. Yield Acceleration vs. Newmark Displacement for the 1992 Landers Earthquake SCE Lucerne Record.

Slope Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where FS is the Factor of Safety, g is the acceleration due to gravity, and α is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure, α is the same as the slope angle.

The yield accelerations resulting from Newmark's equations represent the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. Based on the relationship between yield acceleration and Newmark displacement shown in Figure 2.1, hazard potentials were assigned as follows:

1. If the calculated yield acceleration was less than 0.142g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned (H on Table 2.3).

2. Likewise, if the calculated yield acceleration fell between 0.142g and 0.182g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned (M on Table 2.3).

3. If the calculated yield acceleration fell between 0.182g and 0.243g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned (L on Table 2.3).

4. If the calculated yield acceleration was greater than 0.243g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned (VL on Table 2.3).

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

POINT DUME QUADRANGLE HAZARD POTENTIAL MATRIX

Geologic Material Group	MEAN PHI	SLOPE CATEGORY (% SLOPE)									
		I	II	III	IV	V	VI	VII	VIII	IX	X
		0-10	10-15	15-28	28-34	34-38	38-44	44-48	48-50	50-55	>55
1	35	VL	VL	VL	VL	VL	VL	L	L	M	H
2	32	VL	VL	VL	VL	VL	L	M	H	H	H
3	28	VL	VL	VL	L	M	H	H	H	H	H
4	16	L	M	H	H	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Point Dume Quadrangle. Shaded area indicates hazard potential levels included within the zone of required investigation. H = High, M = Moderate, L = Low, VL = Very Low.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (DOC, 2000). Under these criteria, earthquake-induced landslide hazard zones are defined as areas that meet one or both of the following conditions:

1. Areas that have been identified as having experienced landslide movement in the past, including all mappable landslide deposits and source areas as well as any landslide that is known to have been triggered by historic earthquake activity.

2. Areas where the geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure.

These conditions are discussed in further detail, as follows:

Existing Landslides

Existing landslides typically consist of disrupted soils and rock materials that are generally weaker than adjacent undisturbed rock and soil materials. Previous studies indicate that existing landslides can be reactivated by earthquake movements (Keefer, 1984). Earthquake-triggered movement of existing landslides is most pronounced in steep head scarp areas and at the toe of existing landslide deposits. Although reactivation of deep-seated landslide deposits is less common (Keefer, 1984), a significant number of deep-seated landslide movements have occurred during, or soon after, several recent earthquakes. Based on these observations, all existing landslides with a definite or probable confidence rating are included within the earthquake-induced landslide hazard zone.

No earthquake-triggered landslides had been identified in the Point Dume Quadrangle prior to the Northridge earthquake. The Northridge earthquake caused a number of relatively small, shallow slope failures in and adjacent to the Point Dume Quadrangle (Harp and Jibson, 1995). Rock falls, soil falls, debris falls, and debris slides occurred in poorly indurated or highly fractured sedimentary and volcanic rock on steep slopes and along roadcuts. A slide is reported to have occurred near Latigo Canyon Road in February, 1995, shortly after owners felt ground shaking from a M4.3 earthquake centered near Leo Carrillo State Beach, approximately nine miles from the site (Robertson Geotechnical, Inc., 1996).

Geologic and Geotechnical Analysis

Based on the conclusions of a pilot study performed by DMG (McCrink and Real, 1996), it has been concluded that earthquake-induced landslide hazard zones should encompass all areas that have a High, Moderate or Low level of hazard potential (see Table 2.3). This would include all areas where the analyses indicates earthquake displacements of 5 centimeters or greater. Areas with a Very Low hazard potential, indicating less than 5 centimeters displacement, are excluded from the zone.

As summarized in Table 2.3, all areas characterized by the following geologic strength group and slope gradient conditions are included in the earthquake-induced landslide hazard zone:

1. Geologic Strength Group 5 is included for all slope gradient categories. (Note: Geologic Strength Group 5 includes all mappable landslides with a definite or probable confidence rating).

2. Geologic Strength Group 4 is included for all slopes steeper than 28 percent.

3. Geologic Strength Group 3 is included for all slopes steeper than 38 percent.

4. Geologic Strength Group 2 is included for all slopes steeper than 44 percent.

This results in 54 percent of the land in the Point Dume Quadrangle lying within the earthquake-induced landslide hazard zone.

Landslides attributed to the Northridge earthquake covered approximately 34 acres of land in the quadrangle, which is much less than of 1 percent of the total area covered by the map. Of the area covered by these Northridge earthquake landslides, 94% falls within the area of the hazard zone based on a computer comparison of the zone map and the Harp and Jibson (1995) inventory.

ACKNOWLEDGMENTS

The authors would like to thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project. Geologic material strength data were collected at the City of Malibu with the assistance of Christopher Dean and Jeffrey Wilson (Bing Yen and Associates, geotechnical consultants to the City of Malibu), and Victor Peterson and Martha Graham (City of Malibu). Greg Johnson and Robert Larson (Los Angeles County) provided assistance with data collection for Los Angeles County. Randy Jibson of the U.S. Geological Survey provided digital terrain data. GIS support was provided by Terilee McGuire and Bob Moscovitz. Barbara Wanish and Ross Martin prepared the final landslide hazard zone maps and the graphic displays for this report. Additional information about specific landslides in the area was provided by Greg Johnson, Robert A. Larson, and Robert Thomas (Los Angeles County Department of Public Works), Christopher Dean and Jeffrey Wilson (Bing Yen and Associates, geotechnical consultants to the City of Malibu), and Donald B. Kowalewsky (Environmental and Engineering Geology Consultant).

REFERENCES

*Alpine Geotechnical, 1997, geologic and soils engineering investigation, 5863 Ramirez Canyon Road, Malibu, California: unpublished consultant report dated February 7, 1997.

Brabb, E.E., 1983, Map showing direction and amount of bedding dip of sedimentary rocks in San Mateo County, California: U.S. Geological Survey Miscellaneous Investigations Series Map I-1257C, 1 sheet, scale 1:62,500.

California Department of Conservation, Division of Mines and Geology, 1997, Guidelines for evaluating and mitigating seismic hazards in California: California Department of Conservation, Division of Mines and Geology, Special Publication 117, 74 p.

California Department of Conservation, Division of Mines and Geology, 2000, Recommended criteria for delineating seismic hazard zones: California Department of Conservation, Division of Mines and Geology, Special Publication 118, 12 p.

*California Department of Transportation, 1995, Landslide review – Via Escondido/Sea Vista Drive: unpublished memo by CalTrans dated March 17, 1995.

*Campbell, R. H., 1980, Landslide maps showing field classification, Point Dume Quadrangle, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1167, scale 1 : 24,000.

Campbell, R. H., Yerkes, R. F. and Wentworth, C. M, 1966, Detachment faults in the central Santa Monica Mountains, California: *in*: Geological Survey Research, 1966, U. S. Geological Survey Professional Paper 550-C, C1-C11.

*Campbell, R. H., Blackerby, B.A., Yerkes, R. F., Schoellhamer, J.E., Birkeland, P.W. and Wentworth, C. M, 1996, Geologic map of the Point Dume Quadrangle, Los Angeles, County, California: U.S. Geological Survey Geological Quadrangle Map GQ-1747, scale 1: 24,000.

*Dibblee, T. W., Jr. and Ehrenspeck, H. E., 1993, Geologic map of the Point Dume Quadrangle, Los Angeles and Ventura counties, California: Dibblee Geological Foundation Map DF-48, scale 1: 24,000.

Dibblee, T. W., Jr. and Ehrenspeck, H. E., 1993, Field relations of Miocene volcanic and sedimentary rocks of the western Santa Monica Mountains, California *in* Weigand, P. W. and Davis, G. E., *editors*, Depositional and volcanic environments of middle Tertiary rocks in the Santa Monica Mountains, southern California: Pacific Section – SEPM, Book 72, p.75-92.

*Donald B. Kowalewsky, 1996, Preliminary engineering and soils engineering investigation for proposed single family residence, 6201 De Butts Terrace, Malibu, Los Angeles County, California: unpublished consultant report dated January 30, 1996, Plate 1, Geologic Map, scale 1 inch = 100 feet.

Fritsche, E. A., 1993, Middle Tertiary stratigraphic nomenclature for the Santa Monica Mountains, southern California *in* Weigand, P. W. and Davis, G. E., *editors*, Depositional and volcanic environments of middle Tertiary rocks in the Santa Monica Mountains, southern California: Pacific Section – SEPM, Book 72, p. 1-12.

Fritsche, E. A., Weigand, P.W., Colburn, I.P. and Harma, R.L., 2001, Transverse/Peninsular Ranges connections – evidence for the incredible Miocene rotation *in* Geologic Excursions in Southwestern California: Pacific Section SEPM Book 89, Fieldtrip Guidebook and Volume for the Joint Meeting of the Cordilleran Section GSA and Pacific Section AAPG, p.101-146.

*GeoConcepts, Inc., 1997, Limited geologic and soils investigation– proposed second story addition 27060 Malibu Cove Colony Drive, Malibu, California: unpublished consultant report dated January 20, 1997 and addendum report dated July 22, 1997.

*GeoConcepts, Inc., 1999, Reconnaissance report – proposed second story addition 27040 Malibu Cove Colony Drive, Malibu, California: unpublished consultant report dated October 7, 1999.

*GeoSoils, Inc., 1989, Geologic map – De Butts Terrace, Malibu: unpublished consultant map, WO# 3059-VN dated February, 1989, scale 1 inch = 100 feet.

*Geotechnical Consultants, Inc., 1986, Geotechnical reconnaissance – Indian Head landslide study, Kanan Dume Road, Malibu, California: unpublished consultant report dated June, 1986, prepared for Los Angeles County.

*Gold Coast Geoservices, Inc., 2000, Engineering geologic and geotechnical engineering report, 6156 Ramirez Canyon Road, City of Malibu, California: unpublished consultant report dated June 12, 2000, Plate 1.2, Geologic Map, scale 1 inch = 80 feet.

*Hannah Geotechnical, Inc., 1992, Geological hazards maps: City of Malibu General Plan, (Plates 10 – 18) scale 1: 12,000.

*Harp, E. L. and Jibson, R. W., 1995, Inventory of landslides triggered by the 1994 Northridge, California earthquake: U. S. Geological Survey Open-File Report 95-213, 17 p., Plate 1, scale 1: 100,000.

Horn, B.K.P., 1981, Hill shading and the reflectance map: Proceedings of the IEEE, v. 69, no. 1, p. 14-47.

Hornafius, J.S., Luyendyk, B.P., Terres, R.R. and Kamerling, M.J., 1986, Timing and extent of Neogene tectonic rotation in the western Transverse Ranges, California: Geological Society of America Bulletin, v. 97, p. 1476-1487.

Jibson, R.W., 1993, Predicting earthquake-induced landslide displacements using Newmark's sliding block analysis: Transportation Research Board, National Research Council, Transportation Research Record 1411, 17 p.

Keefer, D.K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, no. 4, p. 406-421.

*Leighton and Associates, Inc., 1986, Geotechnical investigation of Latigo Canyon Road, landslide 2, Malibu, California: unpublished consultant report dated June 23, 1986, Plate 1, scale 1 inch = 100 feet.

*Los Angeles County Department of Public Works, Materials Engineering Division, 1998, Geotechnical report Latigo Canyon Road at culvert marker 4.87: unpublished county report and map dated October 27, 1998, scale 1 inch = 20 feet.

*Los Angeles County Department of Public Works, Materials Engineering Division, 1978, Preliminary geotechnical investigation – Latigo Canyon Road landslide: unpublished county report dated October 4, 1978.

*Los Angeles County Department of Public Works, Materials Engineering Division, 1980, Addendum report – Latigo Canyon Road landslide: unpublished county report dated November 26, 1980.

*Los Angeles County Department of Public Works, Materials Engineering Division, 1993, Latigo Canyon Road failure at mile marker 4.24: unpublished county report dated December 30, 1993.

*Los Angeles County Department of Public Works, Materials Engineering Division, 1984, Marble Head landslide – Kanan Dume Road: unpublished county report dated August, 15, 1984.

*Los Angeles County Department of County Engineer – Facilities, 1980, Preliminary geologic investigation – Kanan Dume Road at mile marker 4.1: unpublished county report dated July 24, 1980.

*Los Angeles County Department of Public Works, Engineering Geology and Soils Group, Land Development Division, 1986, Engineering geology and soils engineering report for the Winding Way – De Butts Terrace project, phase III geotechnical investigation: unpublished county report dated June, 1986, Geologic Maps, Plates 1-9.

McCrink, T.P. and Real, C.R., 1996, Evaluation of the Newmark method for mapping earthquake-induced landslide hazards in the Laurel 7-1/2 minute Quadrangle, Santa Cruz County, California: California Division of Mines and Geology Final Technical Report for U.S. Geological Survey Contract 143-93-G-2334, U.S. Geological Survey, Reston, Virginia, 31 p.

*Mountain Geology, Inc., 1999, Update engineering and geologic report – proposed slope restoration, site stabilization, and repair, 28011 Paquet Place, Malibu, California: unpublished consultant report revised August, 1999, Geologic Map, scale 1 inch = 100 feet.

Newmark, N.M., 1965, Effects of earthquakes on dams and embankments: Geotechnique, v. 15, no. 2, p. 139-160.

*Pacific Geology Consultants, 1998, Report of limited engineering and geologic investigation for proposed construction of a second story addition to existing studio and evaluation of landslide on SE corner of property, 26926 Pacific Coast Highway, City of Malibu, California: unpublished consultant report dated October 19, 1998, Plate A, Geologic Map, scale 1 inch = 100 feet.

Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao. T., Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology, Open File Report 96-08; U.S. Geological Survey Open File Report 96-706, 33 p.

*Phillip Williams & Associates, Ltd. and Peter Warshall & Associates, 1992, Malibu wastewater management study: unpublished report for the City of Malibu, 266 p., fig. III.1, landslide map of the City of Malibu, scale 1: 12,000.

*Robert Stone and Associates, 1969, Grading plan for proposed road and building site, 5930 and 5942 Ramirez Canyon Road, Malibu, California: unpublished consultant report dated September 3, 1969.

*Robertson Geotechnical , Inc., 1996, Engineering geologic and geotechnical engineering exploration – proposed house relocation due to slide, Freedman property, 5837 Latigo Canyon Road, Malibu, California: unpublished consultant report dated February 8, 1996, Geologic Map No. 1, scale 1 inch = 100 feet.

*Roth, E. S., 1959, Landslides between Santa Monica and Point Dume: unpublished M. S. thesis, University of Southern California.

*Shepardson Engineering Associates, Inc., 1991, Geotechnical evaluation of development feasibility, Gulls Way, 26800 Pacific Coast Highway, Malibu, California: unpublished consultant report dated December 30, 1991, Plate 2, Geotechnical Map, scale 1 inch = 40 feet.

Smith, T.C., 1996, Preliminary maps of seismic hazard zones and draft guidelines for evaluating and mitigating seismic hazards: California Geology, v. 49, no. 6, p. 147-150.

*Stoney-Miller Consultants, Inc., 1997, Preliminary geotechnical investigation, south annex landslide stabilization, Gulls Way, Malibu, California: unpublished consultant report dated July 22, 1997, Plate 1, Geotechnical Map, scale 1 inch = 20 feet.

Treiman, J. A., 1994, Malibu Coast Fault, Los Angeles County, California: California Division of Mines and Geology Fault Evaluation Report FER-229, 42 p.

Truex, J. N., 1976, Santa Monica and Santa Ana Mountains – relation to Oligocene Santa Barbara basin: American Association of Petroleum Geologists Bulletin, v. 60, no. 1, p. 65-86.

Truex, J. N., 1977, Santa Monica and Santa Ana Mountains – relation to Oligocene Santa Barbara basin, reply: American Association of Petroleum Geologists Bulletin, v. 61, no. 2, p. 264-269.

*Weber, F, H., Jr., 1980, Landslide and flooding in southern California during the winter of 1979-1980: California Division of Mines and Geology Open-File Report 80-3, 69 p.

*Weber, F. H., Jr., Treiman, J. A., Tan, S.S. and Miller, R. V., 1979, Landslides in the Los Angeles region, California – effects of the February-March 1978 rains: California Division of Mines and Geology Open-File Report 79-4, 277 p., Plate 1, scale 1: 250,000.

*Weber, F. H., Jr. and Wills, C. J., 1983, Map showing landslides of the central and western Santa Monica Mountains, Los Angeles and Ventura counties, California: California Division of Mines and Geology Open-File Report 83-16, scale 1:48,000.

*West Coast Geotechnical, 1995, Update geotechnical engineering report and response to the City of Malibu geologic and engineering review sheet, 6420 Via Escondido, Malibu, California: unpublished consultant report dated October 25, 1995.

Williams, R. E., 1977, Miocene volcanism in the central Conejo Hills, Ventura County, California: unpublished M. A. thesis, University of California, Santa Barbara, 117 p.

Wilson, R.C. and Keefer, D.K., 1983, Dynamic analysis of a slope failure from the 1979 Coyote Lake, California, earthquake: Bulletin of the Seismological Society of America, v. 73, p. 863-877.

Yerkes, R. F. and Campbell, R. H., 1979, Stratigraphic nomenclature of the central Santa Monica Mountains, Los Angeles County, California: U. S. Geological Survey Bulletin 1457-E, p. E1-E31.

Youd, T.L., 1980, Ground failure displacement and earthquake damage to buildings: American Society of Civil Engineers Conference on Civil Engineering and Nuclear Power, 2d, Knoxville, Tennessee, 1980, v. 2, p. 7-6-2 to 7-6-26.

AIR PHOTOS

*Fairchild Aerial Surveys, Flight C300, 1928, Flightline H, Frames H-44 to 46, H-56 to 59, H-69 to 74, H-83 to 88, and Flightline J, J-12 to 16, Black and White, Vertical, scale 1:19,000.

*Fairchild Aerial Surveys, Flight 8666, January 5, 1944, Frames 1-1 to 5, 2-6 to 14, 3-15 to 21, and Flight 8666, January 8, 1944, Frames X-56 to 61, Black and White, Vertical, scale 1: 12,000.

K. Curtis Services, Inc., Ventura County Photos, November 4, 2000, Frames 435-439, Color, Vertical, scale 1: 42,000.

*NASA (National Aeronautics and Space Administration) 04688, Flight 94-002-01, January 21, 1994, Frames 32-40, 41-49, 97-108, 116-125, 183-188, and 265-267, Black and White, Vertical, scale 1:15,000.

*USDA (U.S. Department of Agriculture); Flight AXJ, November 3, 1952; Frames 1K-22 to 27, 1K-37 to 44, 1K-48 to 57, 1K–69 to 77, and Flight AXI, October 7, 1953, Frames 3K-27 to 29, 10K-116 to 121, and 10K-125-126; Black and White; Vertical; scale 1:20,000.

USGS (NAPP Photos), Roll 6860, June 1994, Frames 260-262, Black and White, Vertical, scale 1:40,000.

APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
City of Malibu	**330**
County of Los Angeles	**54**
Malibu Quadrangle	**116**
Total	**500**

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Point Dume 7.5-Minute Quadrangle, Los Angeles and Ventura Counties, California

By

Mark D. Petersen*, Chris H. Cramer*, Geoffrey A. Faneros, Charles R. Real, and Michael S. Reichle

California Department of Conservation
Division of Mines and Geology
***Formerly with DMG, now with U.S. Geological Survey**

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5-minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the “Simple Prescribed Parameter Value” method (SPPV) described in the site investigation guidelines (California Department of Conservation, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2 (addressing liquefaction and earthquake-induced landslide hazards) constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on DMG’s Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology, and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10% probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

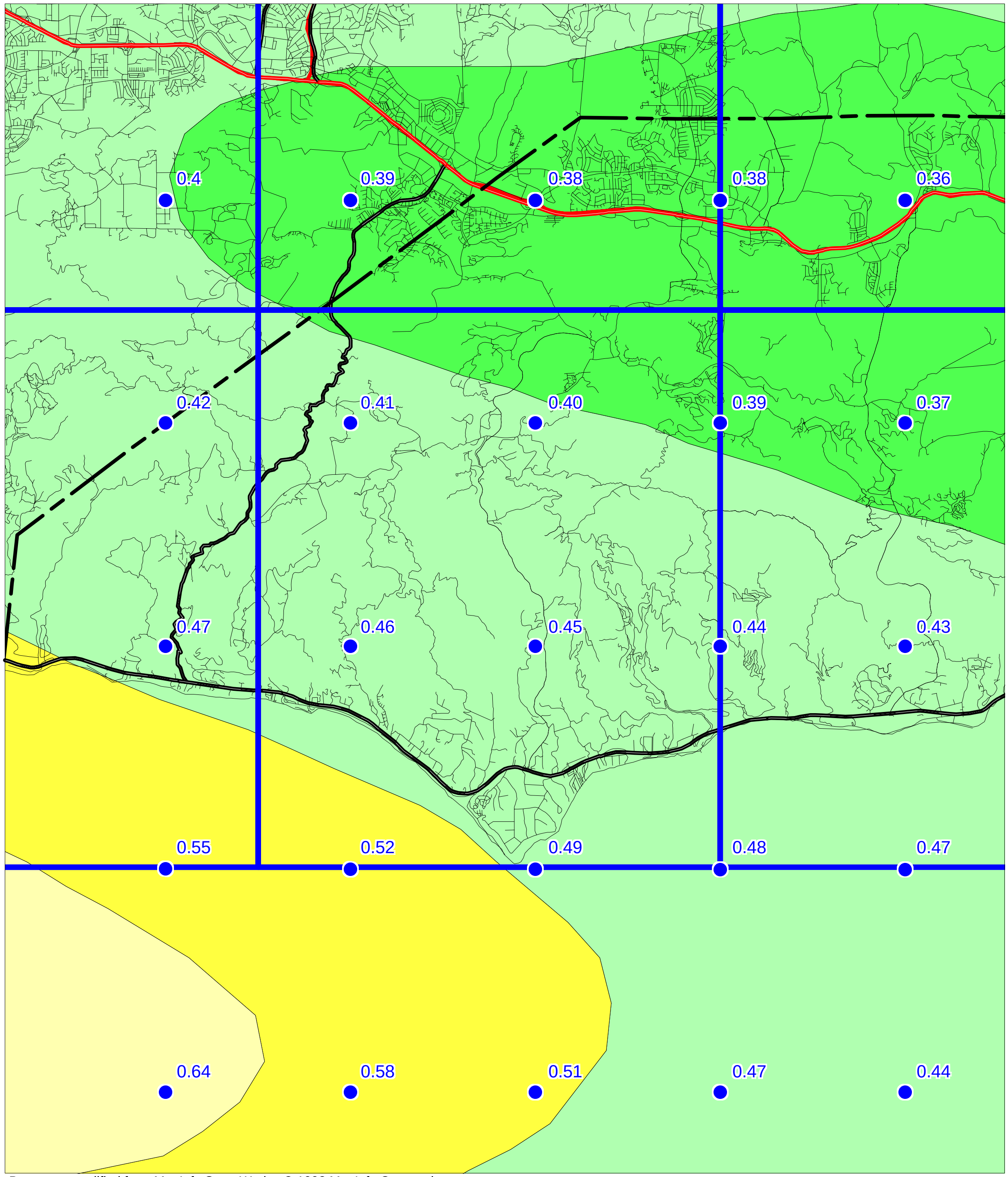
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight adjacent

POINT DUME 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

FIRM ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 2.5 5

Kilometers

Department of Conservation
Division of Mines and Geology

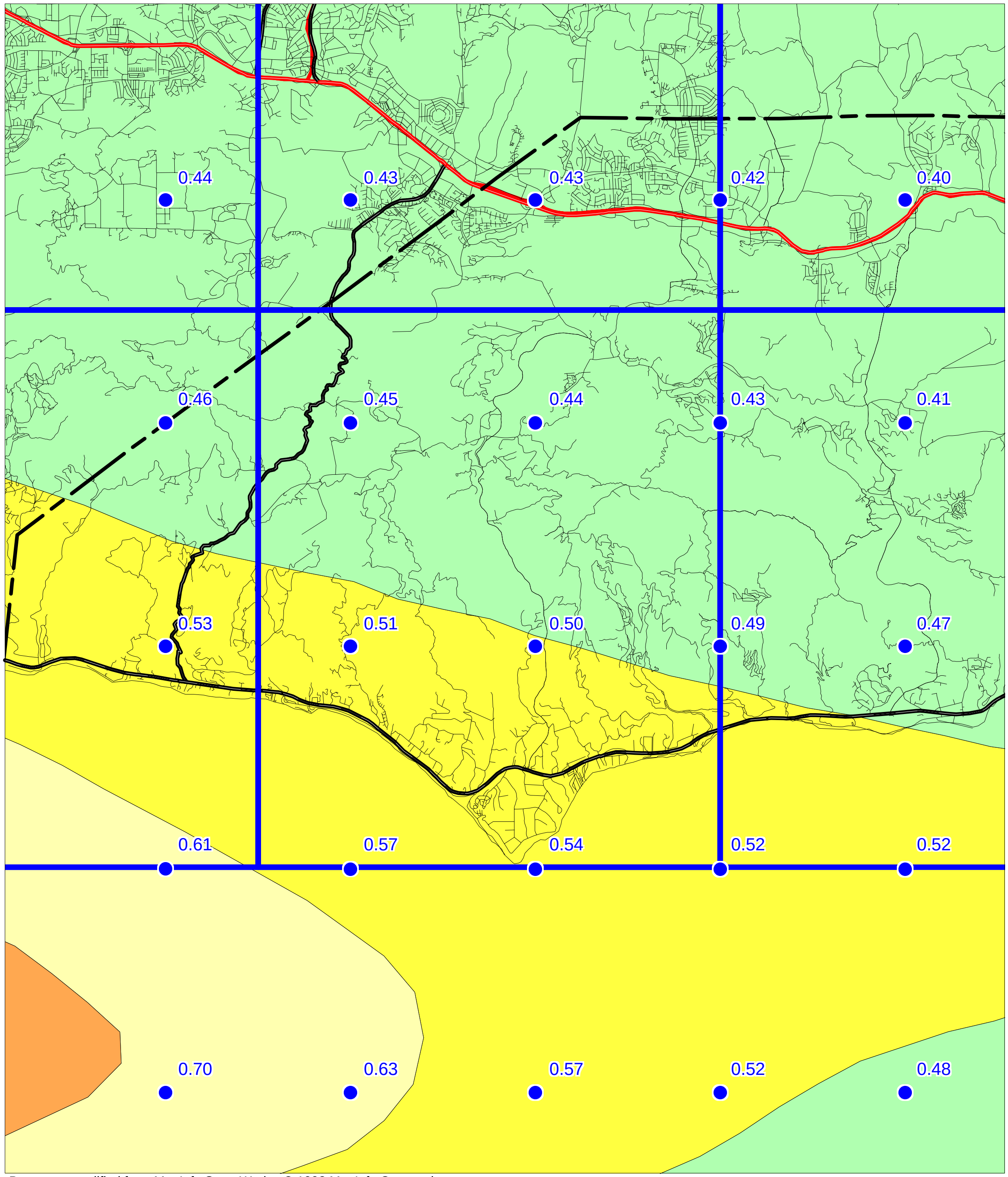
Figure 3.1

POINT DUME 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 2.5 5

Kilometers

Department of Conservation
Division of Mines and Geology

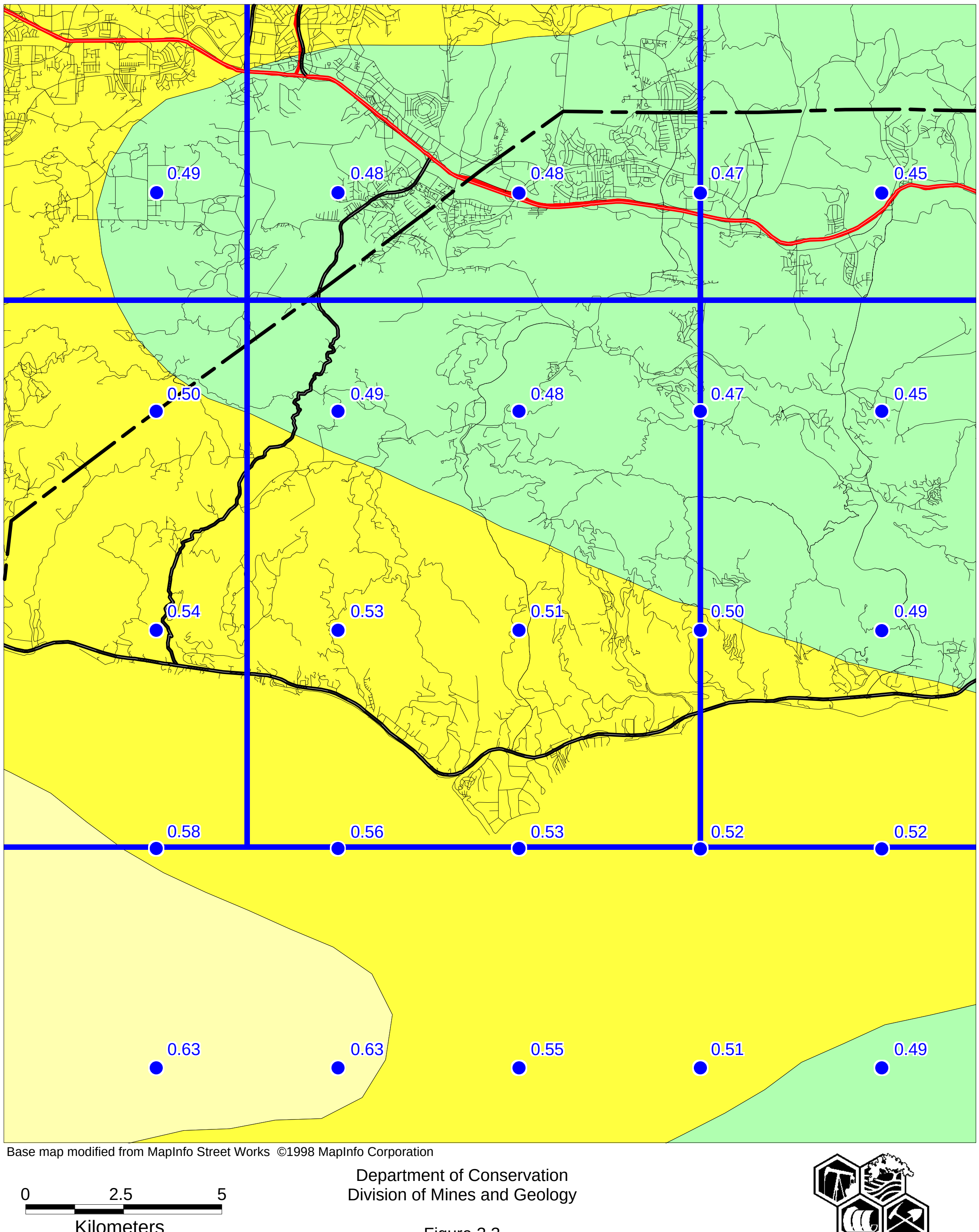
Figure 3.2

POINT DUME 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

ALLUVIUM CONDITIONS



Department of Conservation
Division of Mines and Geology

Figure 3.3

quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10% probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

A preferred method of using the probabilistic seismic hazard model and the “simplified Seed-Idriss method” of assessing liquefaction hazard is to apply magnitude scaling probabilistically while calculating peak ground acceleration for alluvium. The result is a “magnitude-weighted” ground motion (liquefaction opportunity) map that can be used directly in the calculation of the cyclic stress ratio threshold for liquefaction and for estimating the factor of safety against liquefaction (Youd and Idriss, 1997). This can provide a better estimate of liquefaction hazard than use of predominate magnitude described above, because all magnitudes contributing to the estimate are used to weight the probabilistic calculation of peak ground acceleration (Real and others, 2000). Thus, large distant earthquakes that occur less frequently but contribute *more* to the liquefaction hazard are appropriately accounted for.

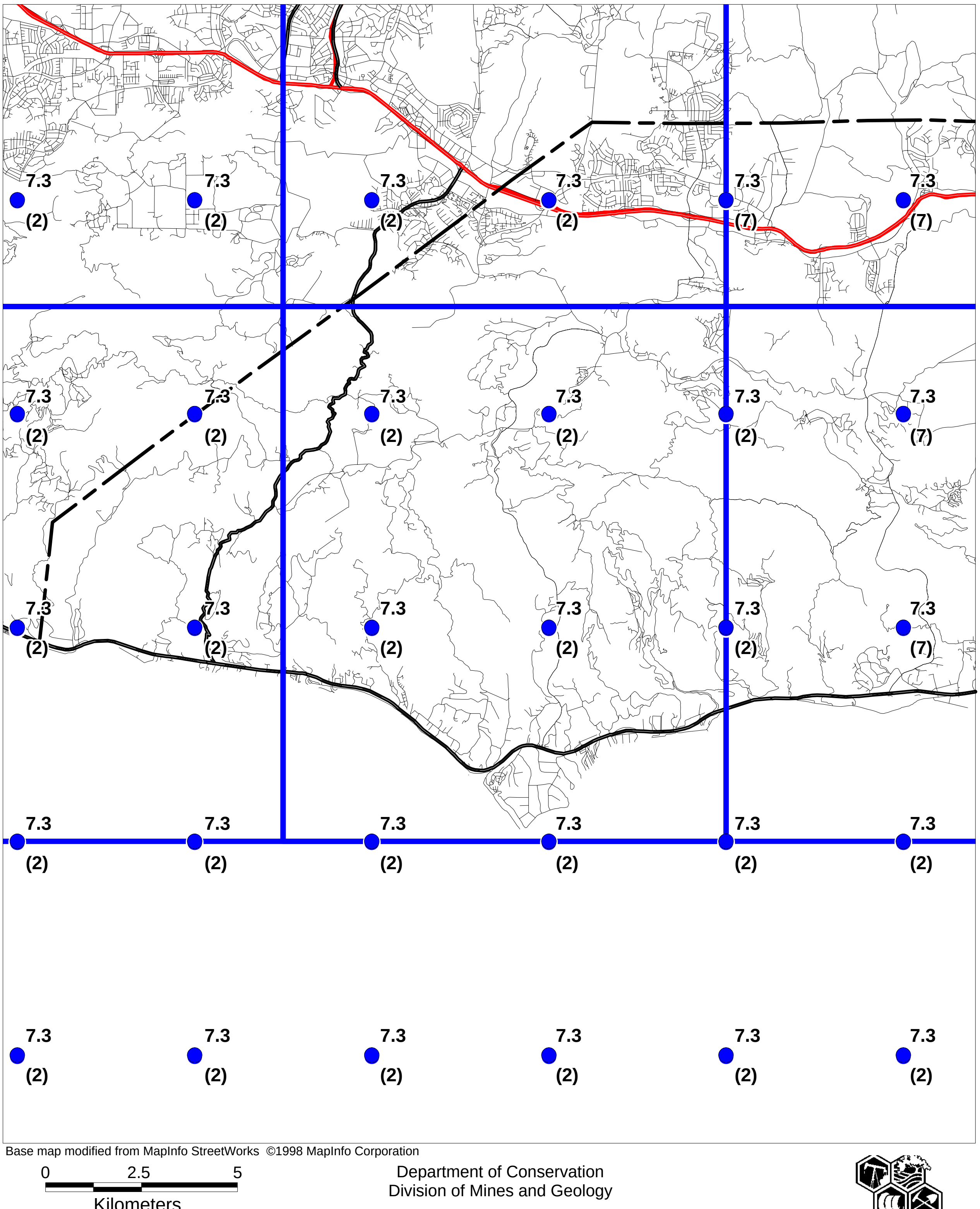
Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss’ weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1) applied.

POINT DUME 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE
Magnitude (Mw)
(Distance (km))



Department of Conservation
Division of Mines and Geology

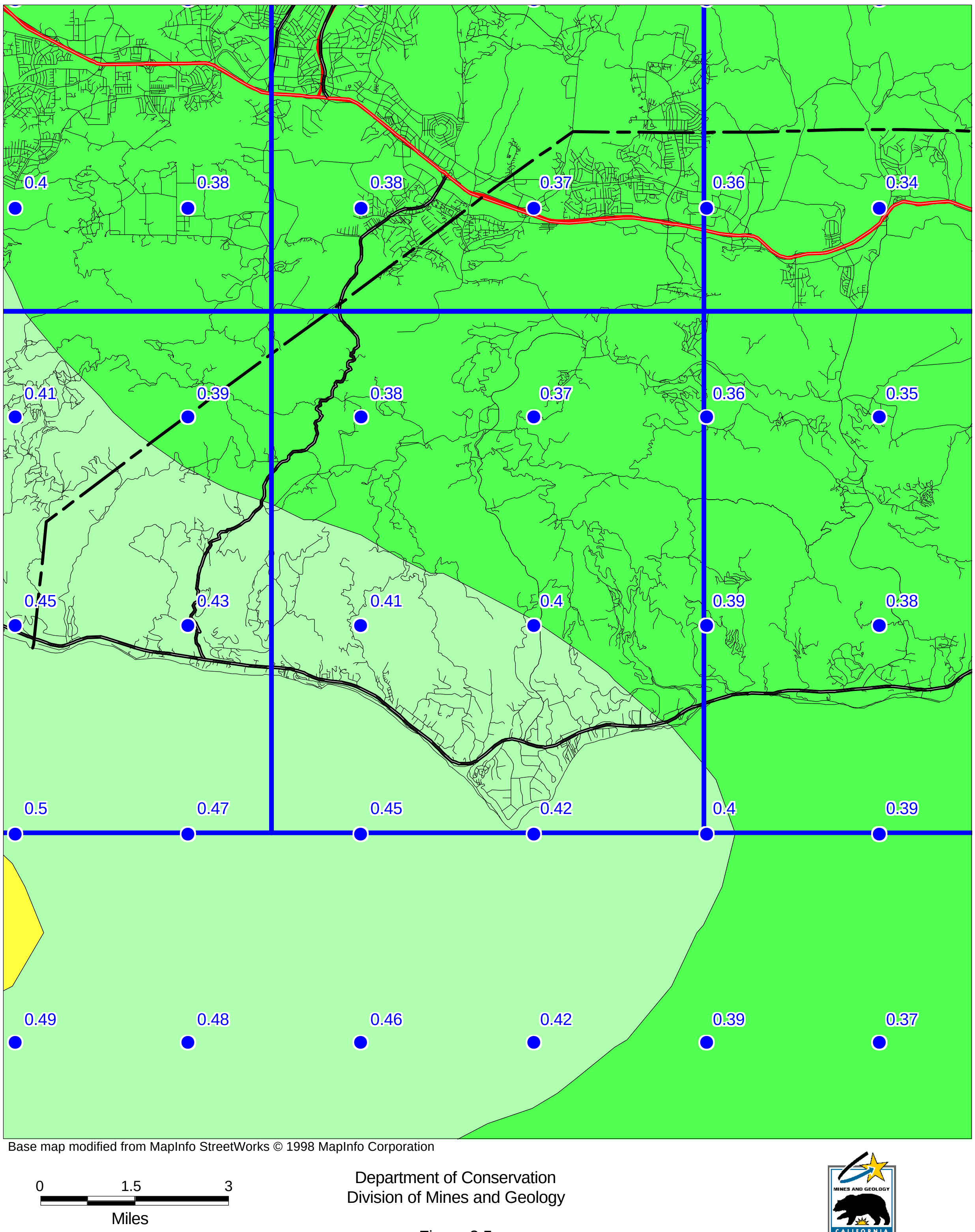
Figure 3.4

POINT DUME 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS MAGNITUDE-WEIGHTED PSEUDO-PEAK ACCELERATION (g) FOR ALLUVIUM

2001

LIQUEFACTION OPPORTUNITY



Department of Conservation
Division of Mines and Geology

Figure 3.5

USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is ***not appropriate for site specific structural design applications***. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.

2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours*.

3. Uncertainties in the hazard values have been estimated to be about +/- 50% of the ground motion value at two standard deviations (Cramer and others, 1996).

4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not been previously recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.

5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

Because of its simplicity, it is likely that the SPPV method (DOC, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the “importance” or sensitivity of the proposed building with regard to occupant safety.

REFERENCES

Boore, D.M., Joyner, W.B. and Fumal, T.E., 1997, Empirical near-source attenuation relationships for horizontal and vertical components of peak ground acceleration, peak ground velocity, and pseudo-absolute acceleration response spectra: Seismological Research Letters, v. 68, p. 154-179.

California Department of Conservation, Division of Mines and Geology, 1997, Guidelines for evaluating and mitigating seismic hazards in California: Special Publication 117, 74 p.

Campbell, K.W., 1997, Attenuation relationships for shallow crustal earthquakes based on California strong motion data: Seismological Research Letters, v. 68, p. 180-189.

Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange and Ventura counties, California: Bulletin of the Seismological Society of America, v. 85, no. 5, p. 1645-1649.

Cramer, C.H., Petersen, M.D. and Reichle, M.S., 1996, A Monte Carlo approach in estimating uncertainty for a seismic hazard assessment of Los Angeles, Ventura, and Orange counties, California: Bulletin of the Seismological Society of America, v. 86, p. 1681-1691.

International Conference of Building Officials (ICBO), 1997, Uniform Building Code: v. 2, Structural engineering and installation standards, 492 p.

Jennings, C.W., *compiler*, 1994, Fault activity map of California and adjacent areas: California Department of Conservation, Division of Mines and Geology, California Geologic Data Map Series, map no. 8.

Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao, T., Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology Open-File Report 96-08; also U.S. Geological Survey Open-File Report 96-706, 33 p.

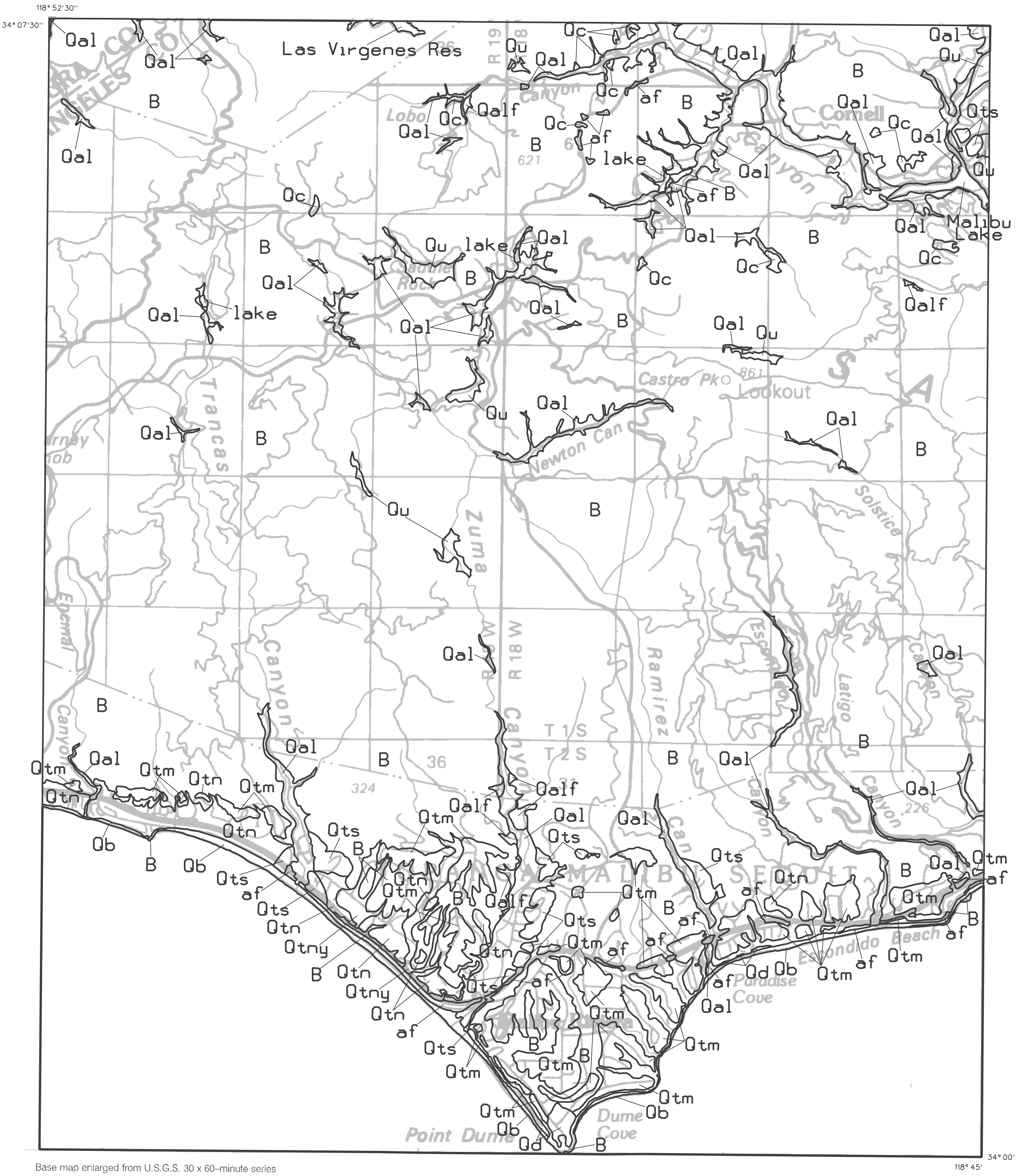
Real, C.R., Petersen, M.D., McCrink, T.P. and Cramer, C.H., 2000, Seismic Hazard Deaggregation in zoning earthquake-induced ground failures in southern California: Proceedings of the Sixth International Conference on Seismic Zonation, November 12-15, Palm Springs, California, EERI, Oakland, CA.

Sadigh, K., Chang, C.-Y., Egan, J.A., Makdisi, F. and Youngs, R.R., 1997, SEA96- A new predictive relation for earthquake ground motions in extensional tectonic regimes: Seismological Research Letters, v. 68, p. 190-198.

Wilson, R.C. and Keefer, D.K., 1983, Dynamic analysis of a slope failure from the 1979 Coyote Lake, California, Earthquake: Bulletin of the Seismological Society of America, v. 73, p. 863-877.

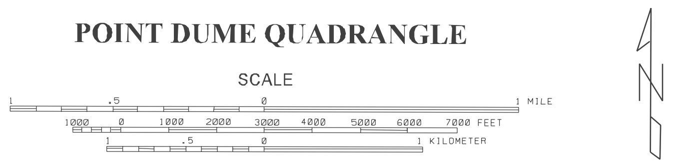
Youd, T.L. and Idriss I.M., 1997, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: Technical Report NCEER-97-0022, 40 p.

Youngs, R.R., Chiou, S.-J., Silva, W.J. and Humphrey, J.R., 1997, Stochastic point-source modeling of ground motions in the Cascadia Region: Seismological Research Letters, v. 68, p. 74-85.



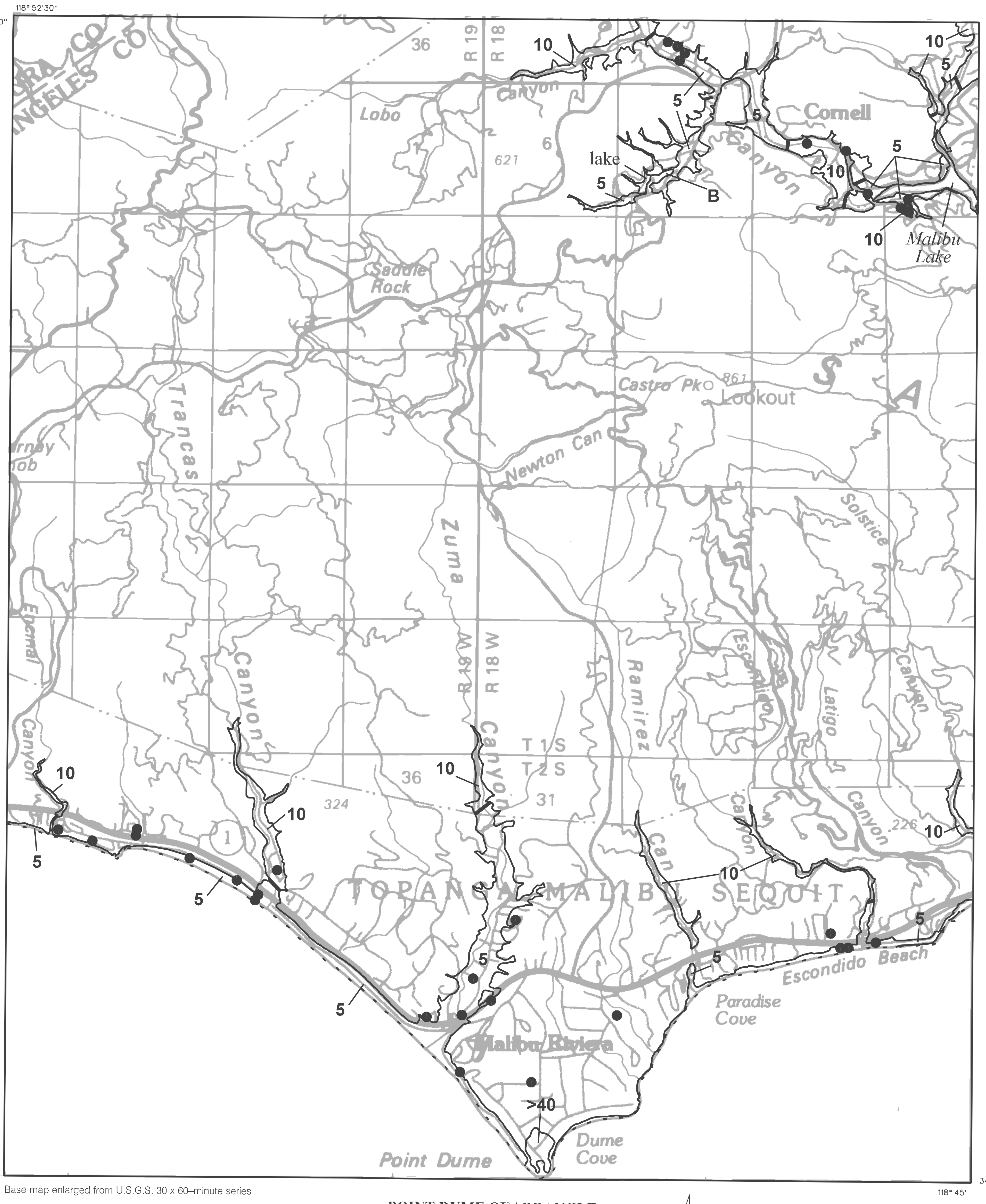
Base map enlarged from U.S.G.S. 30 x 60–minute series

POINT DUME QUADRANGLE



B = Pre-Quaternary bedrock.
See "Bedrock and Surficial Geology" in Section 1 of the report for descriptions of the units.

Plate 1.1 Simplified Quaternary Geologic Map of the Point Dume 7.5-minute Quadrangle (modified from Campbell et al., 1996).



Base map enlarged from U.S.G.S. 30 x 60–minute series

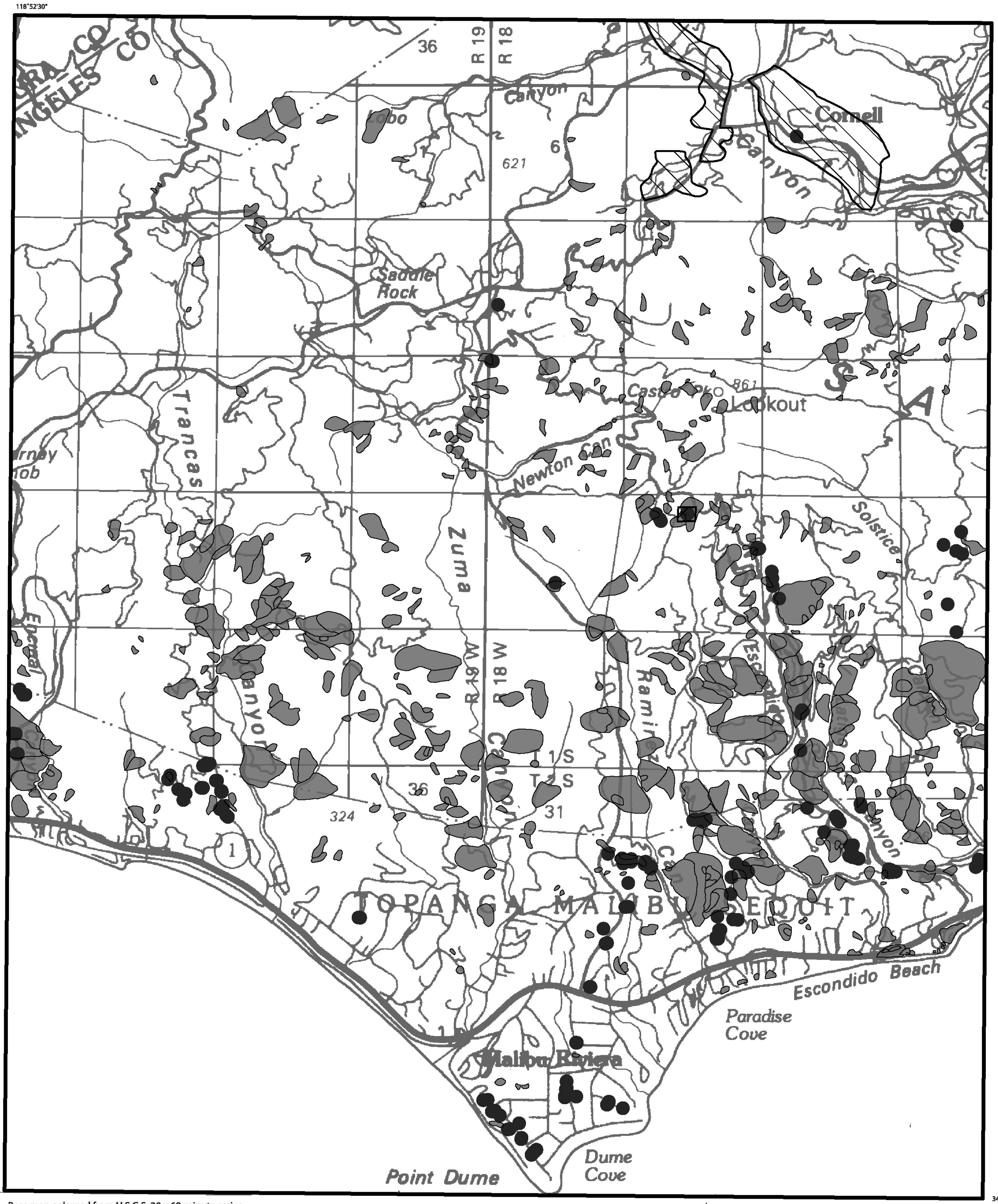
POINT DUME QUADRANGLE

SCALE

● Borehole Site

Estimated historically highest ground-water depth (in feet)
B = Pre-Quaternary bedrock

Plate 1.2 Historically Highest Ground Water within alluviated valleys and Borehole Log Data Locations, Point Dume 7.5-minute Quadrangle.



Base map enlarged from U.S.G.S. 30 x 60-minute series

POINT DUME QUADRANGLE

SCALE

N

Shear test sample location

Landslide

Area of significant grading

Tract report with multiple shear tests

Plate 2.1 Landslide inventory, shear test sample locations, and areas of significant grading, Point Dume 7.5-minute Quadrangle.